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Remedial Process Optimization Phase II Evaluation Report for the Sharpe Defense Distribution Depot, San Joaquin, California

Prepared For



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Consultant Operations Division (AFCEE/ERC)
Brooks Air Force Base
San Antonio, Texas**

and



**Defense Logistics Agency (DLA)
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EXECUTIVE SUMMARY

Parsons Engineering Science, Inc. (Parsons ES) was contracted by the Defense Logistics Agency Environmental Safety and Policy Office (DLA/CAAE) and the Air Force Center for Environmental Excellence Consultant Operations Division (AFCEE/ERC) to conduct a remedial process optimization (RPO) evaluation of remedial decisions and remedial systems at the Sharpe Defense Distribution Depot, San Joaquin, California (DDJC-Sharpe) near Lathrop, California. The general goals for each site addressed under DLA's RPO program are to: 1) assess the effectiveness of selected remedies; 2) enhance the effectiveness and efficiency of the remedies; and 3) when possible, identify optimization opportunities that could result in annual operating, maintenance, and/or monitoring (OM&M) cost savings for the systems evaluated.

The installation is divided into four major areas:

- Administrative and Housing Area in the northern end of the installation;
- North Balloon, located just south of the Administrative and Housing Area;
- South Balloon, at the southern end of the installation; and
- Central Area (the largest part of the installation), occupying the central part of the facility, between the North and South Balloons.

The North and South Balloon areas were apparently used for vehicle storage, as bulk-materials-handling and storage areas, and were served by an extensive rail network. They are named for the distinctive, balloon-like shapes produced by the rail lines that circumscribe each area. Numerous large warehouses occupy much of the Central Area.

DDJC-Sharpe was placed on the National Priorities List in 1987 based on documented contamination of soil and groundwater with volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), fuel hydrocarbons, pesticides/herbicides, and metals. The facility has been organized into several source-area (i.e., soil) solid waste management units (SWMUs) and one groundwater operable unit (OU1) to facilitate the

1 management of environmental restoration activities. Most soil contamination has been or
2 is being remediated. Three sites (sites P-1A/P-1B/P-1C, P-1E, and P-6A) having
3 elevated concentrations of chlorinated solvents in vadose-zone soils are undergoing
4 remediation by soil vapor extraction (SVE) to mitigate continuing sources of
5 groundwater contamination. In groundwater, chlorinated VOCs (primarily
6 trichloroethene [TCE]) are the contaminants detected most frequently and exhibiting the
7 broadest areal distribution in groundwater. Chlorinated VOCs originating at sources in
8 the North Balloon, South Balloon, and Central Area on the facility have migrated to
9 groundwater and are moving off-Depot to the west and northwest in several dissolved-
10 phase plumes.

11 Two Records of Decision (RODs) govern remedial efforts at DDJC-Sharpe. The ROD
12 for OU1 groundwater identifies TCE and a number of other VOCs as groundwater
13 chemicals of concern (COCs), and defines federal or state maximum contaminant levels
14 (MCLs) or action levels as the aquifer cleanup levels (ACLs) for OU1. Under current
15 land-use conditions, no completed groundwater exposure pathways to human or
16 ecological receptors exist on the facility. However, the affected water-bearing unit is
17 classified as a drinking-water source, and restoration of groundwater to drinking-water
18 quality is a statutory requirement. The remedy selected for cleanup of COCs in OU1
19 groundwater involves extraction and treatment of contaminated water; disposal of treated
20 groundwater via discharge to surface water, infiltration to shallow groundwater from
21 percolation ponds, or discharge to the subsurface via injection wells; hydraulic
22 containment to prevent further offsite migration; and long-term monitoring.

23 Four principal “aquifer zones” or “monitoring zones”, referred to as the “A”, “B”,
24 “C”, and “D” zones (with “A” being the uppermost zone and “D” being the deepest) have
25 been distinguished in the upper 270 feet of the hydrogeologic system. The depth
26 intervals corresponding to each monitoring zone are as follow:

- 27 • “A” Zone, extending from the water table (at a depth of 10 to 20 feet below ground
28 surface [bgs]) to a depth of 40 feet bgs;

- 1 • “B” Zone, in the depth interval of 40 to 90 feet bgs;
- 2 • “C” Zone, in the depth interval of 90 to 170 feet bgs;
- 3 • “D” Zone, in the depth interval of 170 to 270 feet bgs.

4 The four zones are not distinguishable on the basis of their hydrogeologic
5 characteristics (e.g., lithology, hydraulic properties, etc.), and do not appear to be
6 separated hydraulically by low-permeability barriers. Furthermore, the monitoring zones
7 are generally in hydraulic communication, so that the complex hydrostratigraphic
8 package of gravel, sand, silt, and clay that extends to a depth of approximately 270 feet
9 bgs actually comprises a single, heterogeneous water-bearing unit.

10 Three independently-functioning groundwater extraction systems remove groundwater
11 from the water-bearing unit at DDJC-Sharpe. The groundwater extraction network in the
12 North Balloon area consists of 18 extraction wells (17 of which are currently in service),
13 with an actual combined total extraction rate of about 260 gallons per minute (gpm). The
14 groundwater extraction network in the Central Area consists of 9 extraction wells with an
15 actual combined total extraction rate of about 480 gpm. The groundwater extraction
16 network in the South Balloon area consists of 18 extraction wells (16 of which are
17 currently in service), with an actual combined total extraction rate of about 180 gpm.
18 Since the first groundwater extraction, treatment, and disposal (ETI) system went into
19 service in 1987, the systems have removed an estimated 700 pounds of TCE from
20 groundwater at the North Balloon, South Balloon, and Central areas. Sampling programs
21 that have varied through time have constrained interpretations of plume continuity, fate,
22 and transport laterally and vertically among the hydrostratigraphic units through time.
23 This has occurred because interpretations of plume continuity and stability can be
24 affected by variations in well density (horizontally and vertically in space) and in the
25 wells sampled during a given monitoring event, presentation of contaminant occurrence
26 by horizon, and incorporation of diluted COC concentrations measured at extraction
27 wells into the evaluation.

1 Groundwater extracted from the North Balloon area is directed to the North Balloon
2 groundwater treatment plant (GWTP), which consists of twin, counter-flow stripping
3 towers in series; a chemical sequestration system; a control building and ancillary
4 equipment; and a discharge pipeline. Groundwater extracted from the South Balloon area
5 is directed to the South Balloon GWTP, which likewise consists of twin, counter-flow
6 stripping towers in series; a chemical sequestration system; a control building and
7 ancillary equipment; and a discharge pipeline. Treated groundwater from the North and
8 South Balloon GWTPs is discharged via the facility storm drain system to the South San
9 Joaquin Irrigation District Canal (SSJIDC), which discharges into French Slough north of
10 the facility. Some of the treated groundwater may be diverted for beneficial use by a
11 neighboring co-generation plant (the Dynegy® plant).

12 As a consequence of elevated levels of arsenic in groundwater extracted from some
13 wells completed in the uppermost (“A”) monitoring zone in the Central Area,
14 groundwater from the “A” zone is managed separately from groundwater extracted from
15 the “B” and “C” zones. Groundwater extracted from the Central Area is directed to the
16 Central Area GWTP, which comprises two separate air-stripping treatment trains (one
17 system for “A”-zone groundwater and a second for groundwater from the “B” and “C”
18 zones), each consisting of twin, counter-flow stripping towers in series; two chemical
19 sequestration systems; a control building and ancillary equipment; two percolation ponds;
20 10 injection wells; and a discharge pipeline. Treated groundwater from the Central Area
21 GWTP is discharged to on-Depot injection wells and percolation ponds, and can also be
22 discharged to the SSJIDC through the storm-drain system. However, discharge from the
23 Central Area treatment plant to the storm drain system is not often utilized, due to
24 occasionally elevated concentrations of arsenic in groundwater from Central Area
25 extraction wells, which is not removed during treatment. Only treated groundwater from
26 the “B”/“C” zones of the Central Area is disposed via injection wells; as a consequence
27 of elevated arsenic concentrations, treated groundwater from the “A” zone is returned to
28 the groundwater system in the shallow subsurface by discharging to percolation ponds for
29 re-infiltration. Treated water from the Central Area may also be diverted to the Dynegy®
30 pipeline.

1 A Base-wide ROD, signed in 1996, affirmed the earlier groundwater ROD, and
2 identified remedies and established cleanup goals for soil at metals-contaminated
3 SWMUs and at VOC-contaminated source areas. Though VOC contaminants in soils do
4 not directly pose unacceptable risks to human or ecological receptors, VOCs in the
5 vadose zone at some sites were judged to represent a continuing threat to groundwater
6 quality. The Base-wide ROD selected remedies for all sites that pose such a threat, and
7 established cleanup goals for soils based on protection/restoration of groundwater quality.
8 Soil remedies included excavation, SVE, institutional controls, and monitoring of
9 groundwater downgradient of source areas for contaminants that had been identified in
10 soil. Three sites currently being remediated using SVE were evaluated during this RPO
11 effort.

12 The following tasks were completed in conjunction with the RPO evaluation for
13 DDJC-Sharpe:

- 14 • Review existing data and the current conceptual site model (CSM) to evaluate
15 previous site characterization activities, remedial decisions, and actions; to assess
16 ongoing remedial system optimization efforts and progress toward ROD objectives;
17 and to identify data gaps;
- 18 • Conduct limited-scale field activities to collect chemical/physical data to assist in
19 evaluating the potential applicability of remediation by natural attenuation of TCE
20 and other VOCs, and to provide information regarding the occurrence of arsenic in
21 groundwater at DDJC-Sharpe;
- 22 • Refine the CSM and develop an alternative strategy for presenting groundwater
23 data, de-emphasizing plume delineation by hydrostratigraphic unit;
- 24 • Review soil cleanup goals established in the ROD and develop alternative site-
25 specific cleanup goals for TCE in vadose-zone soils at sites P-1A/P-1B/P-1C, P-1E,
26 and P-6A;

- 1 • Evaluate the SVE systems in operation at sites P-1A/P-1B/P-1C, P-1E, and P-6A,
2 and identify optimization opportunities;
- 3 • Evaluate the existing OU1 groundwater ETI systems with respect to progress
4 toward achieving the ROD remedial action objectives (RAOs) of plume
5 containment and COC mass removal;
- 6 • Evaluate the long-term groundwater monitoring program; and
- 7 • Prepare this RPO Phase II Evaluation report presenting a refined CSM and
8 optimization recommendations for data compilation and reporting, three SVE
9 systems, and the OU1 ETI systems and groundwater monitoring program.

10 This RPO evaluation resulted in a refinement of the hydrogeologic CSM that could
11 simplify interpretation of contaminant fate and transport in the hydraulically connected
12 saturated units at and downgradient from DDJC-Sharpe.

13 The simplified CSM suggests that the four monitoring zones, which currently are
14 evaluated, discussed, and presented as separate hydrogeologic units in periodic reporting,
15 be recognized as a single unit, and the results of monitoring in the four zones be
16 combined for data interpretation and reporting purposes. To allow clearer presentation of
17 annual monitoring results with respect to interpretations of plume behavior over time, an
18 alternate graphical data-presentation system is proposed that simplifies tracking of
19 groundwater data (and therefore COC plumes) through time, and supports the
20 groundwater monitoring program. Use of the refined CSM and data-reporting strategy
21 would streamline the quarterly and annual monitoring reports without adversely affecting
22 plume interpretations and assessment of remedial progress at OU1.

23 The cleanup goals for VOCs in soil, specified in the ROD for OU2, were reviewed,
24 and site-specific data for sites P-1A/P-1B/P-1C, P-1E, and P-6A were used to develop
25 revised cleanup goals based on modeling of contaminant migration in the unsaturated
26 (“vadose”) zone above the water table. Using an analytical solution describing
27 contaminant migration in the vadose zone (the “Jury model”), it was determined that the

1 ROD-specified cleanup goals for vapor-phase TCE in the vadose zone probably could be
2 increased by 250 to 270 parts per billion by volume (ppbv) at these sites, without
3 representing a continued potential threat to groundwater. If site-specific cleanup goals
4 are accepted by the regulatory authorities, soil cleanup times at the SVE sites could be
5 reduced, with potential cost savings in proportion to the reduction in the period of time
6 required to achieve RAOs for soil. Optimization of the SVE systems at these three sites
7 by targeting hot spots and incorporating passive venting during extraction-system cycling
8 periods could further hasten cleanup for negligible additional cost. In addition,
9 examination of historic, cumulative mass-removal curves for SVE sites P-1E and P-6A
10 indicate that the rate of mass removal at each site has become asymptotic, indicating that
11 little additional TCE mass could be removed from the vadose zone at these sites with
12 continued operation of the SVE systems. The elements required by the Base-wide ROD
13 for terminating SVE operations at these sites appear to have been achieved; and therefore
14 active SVE operations at sites P-1E and P-6A should be discontinued, and the SVE
15 Termination or Optimization Process (STOP) protocol (Castle Air Force Base [AFB],
16 1999) should be implemented at these sites.

17 Little or no contaminant mass removal is occurring at a number of the currently-active
18 groundwater extraction wells, as a consequence of low rates of groundwater withdrawal,
19 low TCE concentrations in extracted groundwater, or both. Based on examination of
20 historic changes in contaminant concentrations in groundwater extraction-well effluent,
21 the minimum times required to achieve ACL concentrations of COCs in groundwater are
22 projected to range from 11 years (in the Central Area) to about 75 years (in the South
23 Balloon area), although longer periods of time may well be required. Several factors are
24 likely to extend the time period needed to attain cleanup goals throughout the plume to
25 periods of decades to perhaps more than 100 years, including slow desorption of
26 contaminants from the soil matrix, and slow release of contaminants by diffusion from
27 low-permeability strata or from “dead-end” pore spaces, and from the solid matrix. The
28 primary capabilities that groundwater extraction-and-treatment systems offer at most sites
29 are hydraulic control of the dissolved contaminant plume, and/or containment of the
30 source zone. Therefore, the preferred strategy for such sites is to pump at the lowest rate

1 necessary to achieve the desired degree of capture of the contaminant flux from the
2 source zone(s). Assessment of the natural-attenuation potential at DDJC-Sharpe
3 indicates that biodegradation processes are destroying COC mass in the subsurface at
4 appreciable rates. If the current groundwater extraction systems are modified to optimize
5 containment and capture of contaminants, the relatively ineffective mass-removal
6 capabilities of the extraction systems will be supplemented by natural-attenuation
7 processes. Therefore, plume containment and hydraulic control of contaminant
8 migration, using the minimum number of wells necessary to effect plume capture, should
9 be the primary goal of groundwater ETI activities at DDJC-Sharpe.

10 If the groundwater extraction systems are optimized for plume containment and
11 hydraulic control, annual cost savings on the order of \$193,000 (in constant 2000 dollars)
12 may be realized. Assuming that the optimized groundwater extraction systems remain in
13 service for the minimum periods of time projected for each system to achieve
14 groundwater RAOs (about 40 years for the North Balloon system, 11 years for the
15 Central Area system, and 75 years for the South Balloon system), total savings in excess
16 of \$9M (in constant 2000 dollars) could result.

17 TCE mass-removal rates at the Central Area "A"-zone GWTP have become
18 asymptotic, suggesting that little additional TCE mass can be removed by continued
19 operation of this system. Evaluation of hydraulic containment and contaminant capture in
20 the Central Area indicates that if the groundwater extraction systems are optimized, the
21 "A"-zone extraction wells in the Central Area could probably be removed from service.
22 If "A"-zone extraction wells in the Central Area are removed from service, the Central
23 Area "A"-zone treatment train could be taken off-line, and arsenic in disposed water
24 would no longer be an issue.

25 The groundwater monitoring program in the South Balloon area also was evaluated
26 and optimized, within a framework that addresses the qualitative, temporal, and spatial
27 aspects of monitoring. The procedures used for the South Balloon groundwater
28 monitoring program could be applied generally to all of DDJC-Sharpe, or to other areas
29 on the facility. Use of diffusion sampling for VOC analysis also was considered, and

1 performance of the incumbent analytical laboratory was reviewed. Based on the review
2 of the remedial decision process and SVE and groundwater extraction system
3 performance to date, and on an evaluation of the groundwater monitoring program at the
4 South Balloon, recommendations were identified to improve SVE and groundwater ETI
5 system performance, optimize the groundwater LTM program, and streamline data
6 reporting in quarterly and annual monitoring reports.

7 Table ES.1 provides a summary of the optimization recommendations, and potential
8 cost savings associated with their implementation, as identified during the RPO
9 evaluation for DDJC-Sharpe. If all recommendations were implemented, annual cost
10 savings of nearly \$600,000 could be realized. Additional, though unquantified, savings
11 could accrue from adopting a simplified CSM; streamlining groundwater data
12 presentation in the annual monitoring reports; and potentially altering the process-stream
13 configuration of two of the GWTPs. Suggestions for implementing the identified RPO
14 opportunities are included in Section 5 of this document.

TABLE ES.1
REMEDIAL OPTIMIZATION RECOMMENDATIONS SUMMARY
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Recommendation	Estimated Annual Cost Savings ^{a/}	Cost Savings Over Life Cycle ^{a/b/}	Difficulty of Implementation	Estimated Cost to Implement ^{a/}
Optimization of Conceptual Model and Data-Presentation Strategy				
Recommendation 1: Simplify the hydrogeologic CSM for DDJC-Sharpe.	TBD ^{c/}	TBD	Moderate – Requires regulatory approval.	\$1 K ^{d/}
Recommendation 2: Revise the data-presentation strategy for tracking COC concentrations and distributions in OU1 groundwater in the annual monitoring reports.	TBD	TBD	Low	\$1 K
Optimization of SVE System				
Recommendation 3: Select and implement site-specific soil cleanup goals.	TBD	TBD	Moderate – Requires regulatory approval.	\$5 K
Recommendation 4: Discontinue active SVE operations at sites P-1E and P-6A.	\$16 K	TBD	Moderate – Requires regulatory approval.	\$5 K
Recommendation 5: Focus SVE to TCE hot spots at the remaining active SVE site(s).	\$24 K	TBD	Low	\$2 K
Recommendation 6: Eliminate offgas treatment of SVE vapor effluent based on system monitoring data.	\$6.4 K	\$160 K	Moderate – Requires regulatory approval.	\$1 K
Recommendation 7: Implement passive extraction of SVE systems during inactive periods of system cycling.	\$2.4 K	\$28.8 K	Moderate – Requires regulatory approval.	\$1 K
Optimization of the OU1 Groundwater ETI Systems				
Recommendation 8: Optimize groundwater ETI systems for plume containment/hydraulic control. Permanently remove 18 existing extraction wells from service. Monitor rebound in inactive wells for one-year period (quarterly monitoring). Continue to monitor groundwater conditions to evaluate long-term plume stability.	\$193 K	>\$9.1 M	Moderate to high – Requires regulatory approval.	\$30 K
Recommendation 9: Remove Central Area “A”-zone treatment train from service. Discontinue disposal of treated water via injection wells and percolation ponds. Route all treated water to the SSJIDC or Dynegy® lines for disposal.	TBD	TBD	Moderate to high – Contingent on Recommendation 8 and subject to regulatory approval	\$15 K

TABLE ES.1 (Continued)
REMEDIAL OPTIMIZATION RECOMMENDATIONS SUMMARY
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Recommendation	Estimated Annual Cost Savings ^{a/}	Cost Savings Over Life Cycle ^{a/b/}	Difficulty of Implementation	Estimated Cost to Implement ^{a/}
Recommendation 10. Consider bypassing the second of the twin stripping towers at the North Balloon and Central Area “B”/“C” GWTPs.	TBD	TBD	Low to moderate – Requires mechanical engineering evaluation of existing circuits.	\$10 K
Optimization of Groundwater Monitoring Program				
Recommendation 11: Revise the existing groundwater monitoring program in the South Balloon area in accordance with the recommended optimization strategy. Conduct a more rigorous spatial-statistical evaluation of the monitoring network at the South Balloon, and implement the results of the spatial evaluation.	\$116 K	\$8.7M	Moderate – Requires regulatory approval.	\$15 K
Recommendation 12: Optimize the groundwater monitoring programs at the North Balloon and Central Area.	\$230 K	\$5.9 M	Moderate – Requires regulatory approval.	\$50 K
Recommendation 13: Evaluate diffusion sampling as a supplemental or replacement technology for the micropurge sampling currently used in the LTM program.	TBD	TBD	Moderate – Requires evaluation of comparability and subsequent regulatory approval.	\$25 K
Recommendation 14: Review the current laboratory selection and auditing process to ensure the contract laboratory is consistently meeting all analytical method requirements, and that pricing for analytical services is competitive.	\$10 K	\$750 K	Low	\$1 K
TOTAL	\$598 K	\$24.6 M		\$160 K

^{a/} Estimated costs presented in constant (year 2000) dollars.

^{b/} Life cycle for SVE system is estimated to be a maximum of 12 years.

Life cycle for conceptual model, data presentation strategy, and operation of some elements of ETI systems is estimated to be 75 years.

Life cycle for groundwater monitoring program is estimated to be 75 years.

^{c/} TBD – To be determined.

^{d/} K – thousands of dollars. M – million of dollars.

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LIST OF ACRONYMS AND ABBREVIATIONS

1		
2	°F	degrees Fahrenheit
3	µg/kg	microgram(s) per kilogram
4	1-D	one dimensional
5	1Q99	first quarter 1999 (typical)
6	ACC	Air Combat Command
7	ACL	aquifer cleanup level
8	AFB	Air Force Base
9	AFBCA	Air Force Base Conversion Agency
10	AFCEE	Air Force Center for Environmental Excellence
11	AFCEE/ERT	Air Force Center for Environmental Excellence/Technology
12		Transfer Division
13	amsl	above mean sea level
14	APCD	Air Pollution Control District
15	ARAR	applicable or relevant and appropriate requirement
16	atm-m ³ /mol	atmospheres-cubic meters/mole
17	BACT	best available control technology
18	bgs	below ground surface
19	bmsl	below mean sea level
20	CAAE	[DLA] Environmental and Safety Policy Office
21	CAH	chlorinated aliphatic hydrocarbon compound
22	CCR	California Code of Regulations
23	CERCLA	Comprehensive Environmental Response, Compensation, and
24		Liability Act
25	CFR	Code of Federal Regulations
26	cm/sec	centimeter(s) per second
27	COC	chemical of concern
28	COPC	chemical of potential concern
29	CPT	cone penetrometer
30	CRWQCB	California Regional Water Quality Control Board
31	CSAL	California State Action Level
32	CSM	conceptual site model
33	day ⁻¹	per day
34	DCA	dichloroethane
35	DCB	dichlorobenzene
36	DCE	dichloroethene
37	DDC	Defense Distribution Center
38	DDD	p,p'-dichlorodiphenyldichloroethane
39	DDE	dichlorodiphenyldichloroethylene
40	DDJC	Defense Distribution Depot San Joaquin, California
41	DDT	4,4'-Dichlorodiphenyltrichloroethane
42	DLA	Defense Logistics Agency
43	DNAPL	dense, nonaqueous-phase liquid
44	DO	dissolved oxygen
45	DOD	US Department of Defense

1	DQO	data quality objective
2	DSERTS	Defense Sites Environmental Restoration Tracking System
3	DTSC	California Department of Toxic Substances Control
4	ESD	Explanation of Significant Difference
5	ESE	Environmental Science and Engineering, Inc.
6	ETA	Engineering Technology Associates, Inc.
7	ETI	extraction, treatment, and injection (disposal) system(s)
8	EW	extraction well
9	Fe ⁺²	Ferrous iron
10	FFA	Federal Facilities Agreement
11	FS	feasibility study
12	ft	feet
13	ft/day	feet per day
14	ft/ft	feet per foot
15	ft/yr	feet per year
16	ft ²	square feet
17	ft ² /day	square feet per day
18	g/cm ³	grams per cubic centimeter
19	GAC	granular activated carbon
20	GHB	General Head Boundary
21	GMS	Groundwater Modeling System
22	gpm	gallons per minute
23	GUI	graphical user interface
24	GWTP	groundwater treatment plant
25	HASP	Health and Safety Plan
26	IRP	Installation Restoration Program
27	ISV	<i>in situ</i> volatilization
28	IWTP	industrial wastewater treatment plant
29	kg	kilogram(s)
30	L	liter(s)
31	lbs/day	pounds per day
32	lbs/year	pounds per year
33	LTM	long-term monitoring
34	MAROS	Monitoring and Remediation Optimization System
35	MCL	maximum contaminant level
36	mg	milligram(s)
37	mg/kg	milligram(s) per kilogram
38	mg/L	milligram(s) per liter
39	Mn	manganese
40	MNA	monitored natural attenuation
41	mV	millivolts
42	MW	monitoring well
43	NAPL	nonaqueous-phase liquids
44	NCP	National Oil and Hazardous Substances Pollution Contingency
45		Plan
46	NFA	no further action

1	NPDES	National Pollutant Discharge Elimination System
2	NPL	National Priorities List
3	O&M	operation and maintenance
4	OM&M	operations, maintenance, and monitoring
5	OPS	operating properly and successfully
6	ORP	oxidation-reduction potential
7	OSWER	Office of Solid Waste and Emergency Response
8	OU	Operable Unit
9	Parsons ES	Parsons Engineering Science, Inc.
10	PCB	polychlorinated biphenyl compound
11	PCE	tetrachloroethene
12	POL	petroleum fuels, oils, and lubricants
13	ppbv	part(s) per billion, volume per volume
14	ppmv	part(s) per million, volume per volume
15	QA	quality assurance
16	RA	risk assessment
17	Radian	Radian International LLC <i>or</i> Radian URS
18	RAO	remedial action objective
19	RBCA	risk-based corrective action
20	RCRA	Resource Conservation and Recovery Act
21	redox	reduction/oxidation
22	RI	remedial investigation
23	ROD	record of decision
24	ROI	radius of influence
25	RPO	remedial process optimization
26	RSV	remedial process optimization scoping visit
27	RWQCB	Regional Water Quality Control Board
28	SAP	sampling and analysis plan
29	SARA	Superfund Amendments and Reauthorization Act of 1986
30	scfm	standard cubic feet per minute
31	SJVUAPCD	San Joaquin Valley Unified Air Pollution Control District
32	SOW	statement of work
33	SSJIDC	South San Joaquin Irrigation District Canal
34	STOP	SVE termination or optimization process
35	SVE	soil-vapor extraction
36	SVOC	semi-volatile organic compound
37	SWMU	solid waste management unit
38	SWRCB	State Water Resources Control Board
39	TBC	to-be-considered criterion
40	TCA	trichloroethane
41	TCE	trichloroethene
42	TDS	total dissolved solids
43	TOC	total organic carbon
44	TPH	total petroleum hydrocarbon compounds
45	US	United States
46	USACE	United States Army Corps of Engineers

1	USAEC	United States Army Environment Center
2	USAF	United States Air Force
3	USATHAMA	United States Army Toxic and Hazardous Materials Agency
4	USC	United States Code
5	USDOD	U.S. Department of Defense
6	USEPA	United States Environmental Protection Agency
7	UST	underground storage tank
8	UTL	upper tolerance limit
9	VC	vinyl chloride
10	VEW(s)	vapor extraction well(s)
11	VMP(s)	vapor monitoring point(s)
12	VOA	volatile organics analysis
13	VOC(s)	volatile organic compound(s)
14	WDR	Waste Discharge Requirement
15	WES	Waterways Experiment Station
16	WET	waste-extraction test
17	WHPA	Wellhead Protection Area
18	yd ³	cubic yard(s)
19	µg	microgram(s)
20	µg/L	microgram(s) per liter

1 **SECTION 1**
2
3 **INTRODUCTION**
4

5 On 21 March 2000, Parsons Engineering Science, Inc. (Parsons ES) was awarded a
6 task order under the United States Air Force (USAF) Air Combat Command (ACC)
7 contract (F44650-99-D0005, RL 72) to support remedial process optimization (RPO)
8 scoping visits and to conduct RPO Phase II evaluations at selected Defense Logistics
9 Agency (DLA) locations. The United States (US) Air Force Center of Environmental
10 Excellence, Technology Transfer Division (AFCEE/ERT) provides technical oversight of
11 this task order. RPO evaluations completed under the task order are conducted in
12 accordance with procedures described in the US Air Force's draft final RPO Handbook,
13 developed by Parsons on behalf of AFCEE and the Air Force Base Conversion Agency
14 (AFBCA) (AFCEE and AFBCA, 1999).

15 The general objectives of an RPO evaluation are to review the performance of existing
16 remediation systems, recommend performance enhancements to existing systems, assist
17 in performing 5-year Record-of-Decision (ROD) reviews, and assist in preparation of
18 documentation for "Operating Properly and Successfully" (OPS) certification. The
19 primary objective of the RPO at the Defense Distribution Depot, San Joaquin, California
20 (DDJC) Sharpe facility (DDJC-Sharpe) was to assess the performance of the active
21 remediation systems, with the goal of improving their effectiveness and reducing overall
22 site cleanup costs while ensuring protectiveness of human health and the environment.

23 **1.1 DESCRIPTION OF THE RPO PROCESS**

24 RPO is a systematic approach for evaluating and improving the effectiveness of site
25 remediation. Ideally, the time required to achieve remediation objectives may be
26 decreased as a result of the findings and recommendations of an RPO evaluation, and
27 overall project costs may be reduced. Although RPO is frequently associated with the

1 optimization of remediation systems and *how* the cleanup will be completed, it also
2 reviews *why* certain cleanup goals have been established and to update those decisions
3 based on new regulatory options. Just as the technical approach to remediation should be
4 upgraded to take advantage of scientific advances, changes in regulatory framework such
5 as adoption of risk-based cleanup goals and the growing acceptance of monitored natural
6 attenuation (MNA) must be considered in the optimization process. An effective RPO
7 program will pursue a wide range of optimization opportunities

8 RPO has many potential benefits, including identifying the most effective remediation
9 options, improving tracking of remedial progress and protectiveness, reducing operating
10 costs, optimizing monitoring systems with concomitant reductions in analytical costs,
11 reevaluating remedial action objectives (RAOs) and cleanup goals, improving regulatory
12 feedback, and accelerating site transfer and closure.

13 **1.2 SCOPE AND OBJECTIVES OF RPO AT DDJC-SHARPE**

14 This report presents the results of the RPO Phase II evaluation conducted at DDJC-
15 Sharpe. The specific objectives of this RPO evaluation, and the tasks to be completed by
16 Parsons in conjunction with the evaluation, were initially presented in the *Final Remedial*
17 *Process Optimization Work Plan for the Sharpe Defense Distribution Depot San Joaquin,*
18 *California* (Parsons ES, 2000), and are summarized below. Objectives of the Phase II
19 RPO project at DDJC-Sharpe included:

- 20 • Evaluate the accuracy of the conceptual hydrogeologic site model (CSM), and the
21 appropriateness of cleanup goals and data quality objectives (DQOs);
- 22 • Review existing decision structures or establish decision trees for evaluating
23 performance and effectiveness of remedial systems;
- 24 • Assess the effectiveness of the current remediation systems and planned remedial
25 measures in relation to existing performance criteria;

- 1 • Verify that operation, maintenance and monitoring (OM&M) procedures and
2 analytical protocols are appropriate and will meet the DQOs of the groundwater
3 remediation systems;
- 4 • Develop recommendations for optimizing remedial systems operations,
5 performance monitoring, and long-term monitoring programs that could potentially
6 generate future cost savings;
- 7 • Streamline and standardize data management systems dealing with cost,
8 performance, and monitoring;
- 9 • Identify long-term opportunities for the direction of future remedial decision
10 making; and
- 11 • Provide a plan for implementing appropriate short-term recommendations and
12 long-term opportunities.

13 Specific tasks that were completed during this RPO Phase II evaluation for DDJC-
14 Sharpe included:

- 15 • Conducting a preliminary site visit and review of the administrative record and
16 other information regarding environmental investigations and the historic
17 performance of remedial systems at DDJC-Sharpe;
- 18 • Reviewing available data generated during site investigations, studies, remedial
19 actions, and monitoring;
- 20 • Preparing a site-specific work plan (Parsons ES, 2000);
- 21 • Collecting chemical/physical data to fill data gaps, as warranted;
- 22 • Refining the CSM, as appropriate, based on new data and review of existing
23 information;
- 24 • Evaluating the remedial decision process that formed the basis for system designs
25 and the current applicability of the established RAOs;

- 1 • Evaluating the existing groundwater extraction, treatment, and discharge/re-
2 injection/re-infiltration (ETI) systems, monitoring networks, and long-term
3 monitoring plans with respect to established RAOs;
- 4 • Evaluating fate and movement of contaminants in the subsurface at DDJC-Sharpe,
5 assessing the possible occurrence of natural attenuation of contaminants;
- 6 • Identifying possible alternative technologies or approaches for achieving RAOs at
7 DDJC-Sharpe;
- 8 • Evaluating a subset of the monitoring well network and identifying opportunities
9 for optimizing the monitoring program that might be associated with adjustments
10 sampling locations, frequencies, analytes, or sampling and analysis techniques; and
- 11 • Preparing this RPO Phase II evaluation report and presenting conclusions regarding
12 the system evaluations and RPO recommendations for DDJC-Sharpe.

13 **1.3 DOCUMENT ORGANIZATION**

14 This RPO report presents an overview of environmental conditions at DDJC-Sharpe,
15 briefly describes the existing remediation systems and their operational history, provides
16 a review of the existing regulatory framework, discusses potential optimization
17 opportunities for remediation systems at DDJC-Sharpe, and presents a plan and schedule
18 for implementation of recommendations for system optimization. The report is organized
19 into seven sections, including this introduction, and five appendices. Section 1 provides a
20 review of the site history and background information for DDJC-Sharpe. Current site
21 conditions, including the environmental setting and nature and extent of contamination,
22 are described in Section 2, together with a discussion of the conceptual site model (CSM)
23 and a summary of refinements to the CSM, and an evaluation of natural attenuation
24 processes that are occurring at DDJC-Sharpe. Section 3 includes an evaluation of site
25 cleanup goals and a review of RAOs and ROD requirements. The current and potential
26 future effectiveness of remedial systems at DDJC-Sharpe is examined in Section 4.
27 Section 5 presents recommendations for RPO opportunities, and provides suggestions for
28 implementing the recommendations. Section 6 lists the references cited in this document.

Appendix A consists of a CD-ROM disk, containing electronic files that include the analytical data collected by Parsons in July 2000. A brief discussion of chemical properties and natural attenuation processes, and the resulting effects on chemical fate in the environment, is provided in Appendix B. The unsaturated-zone contaminant transport modeling, used to evaluate cleanup goals for soil in the vadose zone, is described in Appendix C. The detailed results of capture-zone analyses of the groundwater extraction systems are provided in Appendix D; and the results of the statistical analysis of the groundwater monitoring network at the South Balloon area are presented in Appendix E.

1.4 DESCRIPTION OF FACILITY

1.4.1 Location and Operational History

DDJC-Sharpe is located within the San Joaquin Valley, approximately 9 miles south of Stockton, California (Figure 1.1). The installation occupies an approximately rectangular parcel of land about 0.5 mile wide (in the east-west direction) and 2 miles long (from north to south), and encompasses approximately 720 acres (Figure 1.2). Since the beginning of its operational history in 1941, DDJC-Sharpe has fulfilled supply and maintenance missions. The supply mission, which is the current mission for the Depot, includes storage, handling, preservation, packaging, and shipment of general supplies and equipment for US armed forces worldwide. The maintenance mission, which was terminated in 1976, included repair and reconditioning of military heavy equipment and aircraft. The mission of maintaining heavy equipment was initiated in the late 1940s, and aircraft-maintenance was added in 1957. The primary waste-generating activities associated with these operations were painting, paint stripping, and metal finishing. Other activities included engine overhauls, hydraulic- and electrical-system repairs, airframe repair and body work, and repair and reconditioning of vehicle and aircraft components.

The installation is divided into four major areas (Figure 1.2):

- Administrative and Housing Area in the northern end of the installation;

1 **Figure 1.1 Vicinity Map**

2

1 **Figure 1.2 Site Map**

2

- North Balloon, located just south of the Administrative and Housing Area;
- South Balloon, at the southern end of the installation; and
- Central Area (the largest part of the installation), occupying the central part of the facility, between the North and South Balloons.

The North and South Balloon Areas were apparently used for vehicle storage and as bulk-materials-handling and storage areas, and were served by an extensive rail network. They are named for the distinctive, balloon-like shapes produced by the rail lines that circumscribe each area (Figure 1.2). Numerous large warehouses occupy much of the Central Area. An aircraft hangar and abandoned runway are located near the western boundary of the Central Area.

1.4.2 Previous Investigations

Contaminants were first detected in soil and groundwater at DDJC-Sharpe in 1982, when the U.S. Army Environment Center (USAEC) (formerly the US Army Toxic and Hazardous Materials [USATAHMA, 1982]) conducted a site assessment. The results of the assessment indicated that groundwater contaminated with dissolved volatile organic compounds (VOCs) was migrating off-Depot (Battelle Pacific Northwest Laboratories, 1983). Based on the results of that study, a remedial investigation (RI) was initiated by Environmental Science and Engineering, Inc. (ESE, 1987), on behalf of the USAEC, to evaluate the nature and extent of facility-related contaminants in groundwater. Chlorinated solvents, primarily trichloroethene (TCE), but also including tetrachloroethene (PCE), dichloroethene isomers (1,1-DCE, *cis*-1,2-DCE, and *trans*-1,2-DCE), trichloroethane isomers (1,1,1-TCA and 1,1,2-TCA), dichlorobenzene isomers (1,2-DCB and 1,4-DCB), and carbon tetrachloride, were detected in groundwater during the RI, and were designated in the ROD for groundwater at DDJC-Sharpe (ESE, 1993a) as the principal chemicals of potential concern (COPCs) in groundwater. Available data indicate that VOC contamination is probably associated with past mission-related activities (e.g., vehicle maintenance) at DDJC-Sharpe. Because the available information indicated that VOCs in groundwater had migrated off-facility, and could potentially threaten potable groundwater wells west of the facility, DDJC-Sharpe was added to the

1 NPL in 1987 (Table 1.1). Groundwater contaminant plumes originating on the facility
2 were designated as Operable Unit 1 (OU1). Semi-volatile organic compounds (SVOCs)
3 were eliminated as chemicals of concern (COCs) during the early phases of the RI.
4 Arsenic, selenium, nitrates, and bromacil also have been detected sporadically in
5 groundwater samples.

6 Based on the results of investigations conducted at DDJC-Sharpe between 1982 and
7 1989, two groundwater extraction and treatment systems were installed as interim
8 remedial measures (one system at each of the South Balloon Area and North Balloon
9 Area), and began operation in March 1987 and October 1990, respectively, to limit
10 further migration of contaminated groundwater (Tables 1.1 and 1.2). Treated water was
11 returned to the uppermost water-bearing unit via injection wells and percolation ponds.

12 The final RI was completed in 1988 (ESE, 1988), and the feasibility study (FS) for
13 groundwater contamination at OU1 was completed the following November (ESE,
14 1991a). The final ROD for OU1 groundwater was issued in January 1993 (ESE, 1993a).
15 The ROD identified groundwater extraction and treatment (“pump-and-treat”) as the
16 selected remedy for groundwater, with VOCs, arsenic, selenium, bromacil, and nitrates
17 identified as groundwater COCs. A third groundwater extraction system and treatment
18 plant was installed in the Central Area, and began operation in May 1995 (Tables 1.1 and
19 1.2). Currently, groundwater extraction, treatment, and disposal (infiltration, injection, or
20 other discharge) (ETI) systems are operating in the South Balloon Area, North Balloon
21 Area, and Central Area in accordance with the requirements of the ROD for OU1.

22 Contaminated soils at DDJC-Sharpe have been designated as OU2. The soils FS,
23 which addressed TCE-, lead-, and chromium-contaminated soils, and identified sites
24 recommended for no further action (NFA), was completed in December 1994 (ESE,
25 1994a). Limited soil remediation has been conducted to date, and has consisted primarily
26 of removal actions for metals-contaminated soil, and removal or *in-situ* treatment of
27 petroleum-hydrocarbon-contaminated soils in the vicinity of leaking underground storage
28 tanks (USTs). In December 1992, approximately 3,000 cubic yards (yd³) of soils
29 contaminated with petroleum constituents was excavated from the North Balloon Area

1

2

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4

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TABLE 1.1
ENVIRONMENTAL PROGRAM MILESTONES
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

1987	Installation added to NPL
1987	Installation and operation of interim groundwater extraction and treatment system in the South Balloon
1989	FFA signed
1989	Interim RI/FS for North Balloon
1990	Installation and operation of interim groundwater extraction and treatment system in the North Balloon
1991	Groundwater FS performed
1991	RI completed
1991	FFA amended
1992	Soils FS and risk assessment completed
1992	OU 1 groundwater proposed plan published
1992	Total petroleum hydrocarbon (TPH)-contaminated North Balloon soils removal action conducted
1993	OU 1 ROD signed
1994	RI/FS – Soils FS/risk assessment report completed
1995	Draft basewide remedy ROD signed
1995	Installation and operation of groundwater extraction and treatment system in Central Area
1995	OU 2 proposed plan published
1995	Pesticide -contaminated North Balloon soils removal action conducted
1996	Final basewide remedy ROD signed
1997	Full operation of Central Area extraction and treatment system implemented
1998	Contaminated soil removal actions in North and South Balloons
1998-1999	Installation and operation of SVE systems in the South Balloon and Central Area

Abbreviations:

DDJC Defense Distribution Depot San Joaquin, California
FFA Federal Facility Agreement
FS feasibility study
NPL National Priorities List
OU operable unit
RI remedial investigation
ROD Record of Decision
SVE soil vapor extraction
TPH total petroleum hydrocarbon compounds

6

Source: Radian (1999f)

TABLE 1.2
SUMMARY OF PREVIOUS INSTALLATION RESTORATION PROGRAM INVESTIGATIONS AT DDJC-SHARPE
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Year, Contractor	Scope of Investigation	Data Collected
Field Investigation		
1989-1991, US Army Toxic and Hazardous Materials Agency	RI/FS; soil and groundwater sampling and analyses	Contaminant concentrations in soil and groundwater
1985-1995, Environmental Science and Engineering, Inc.	Groundwater sampling, RI/FS, and extraction well design; UST conditions evaluation; engineering evaluation/cost analysis-Pesticide Mix Area	Groundwater contaminant concentration data Groundwater elevation data Pump testing Soil sampling and analysis
1989-1999, Radian International	Operation, maintenance and optimization of Central and South Balloon soil vapor extraction systems	Flow Rates Analytical data Vacuum levels Operation temperatures
1992-1994, DDJC-Sharpe	Quarterly and annual groundwater monitoring reports	Groundwater contaminant concentrations Groundwater elevation contours
1992-1994, Quality Assurance Laboratory, Inc.	NPDES sampling and analysis	Concentrations in effluent from groundwater treatment systems
1995, Pacific Treatment Analytical Services, Inc.	Quarterly groundwater monitoring well sampling and analysis	Groundwater levels Analytical data
1996, Radian International	UST site characterization (Sites 12, 15, 17, 17, 49/55, 73, Sump 669)	Soil samples Extent of TPH contamination in water and soil

TABLE 1.2 (Continued)
SUMMARY OF PREVIOUS INSTALLATION RESTORATION PROGRAM INVESTIGATIONS AT DDJC-SHARPE
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Year, Contractor	Scope of Investigation	Data Collected
1995-1999, Radian International	Annual groundwater monitoring report	Groundwater contaminant concentrations Groundwater elevation contours
1996-1999, Radian International	NPDES sampling and analysis	Concentrations in effluent from groundwater treatment system
1996-1999, Radian International	Quarterly groundwater monitoring well sampling, analysis, and reporting	Groundwater levels Analytical data
1997, Radian International	UST site investigations (Sites 146 and 147)	Soil samples Extent of TPH contamination in water and soil
1997, Radian International	Bioventing pilot test at UST Site 17	Soil samples, soil gas samples Monitoring points constructed
1998, Radian International	DNAPL, Investigation at MW-455	Groundwater data
1998, Radian International	Site S-33/29 metals investigation	Soil and groundwater data
Pre-Design Investigations		
1992, Engineering Technologies Associates, Inc.	Three-dimensional modeling for extraction well field design	Groundwater levels Aquifer test data Total organic carbon analyses
1992-1994, James M. Montgomery/Montgomery Watson	Pre-design and remedial design work plan for Central Area extraction system	lithologic data Groundwater data Construction data
1995, Radian International	<i>In-situ</i> volatilization performance review	Soil gas analyses and geology
1997, Radian International	Pre-design technical summary for Operable Unit 2	Extent of VOC and metals contamination in soil and soil gas

TABLE 1.2 (Continued)
SUMMARY OF PREVIOUS INSTALLATION RESTORATION PROGRAM INVESTIGATIONS AT DDJC-SHARPE
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Year, Contractor	Scope of Investigation	Data Collected
Post-Construction Investigation		
1995, Environmental Science and Engineering, Inc.	Startup treatment performance evaluation, and prove-out phase for Central Area extraction system	Flow rates Groundwater levels Analytical; data
1995-1996, Environmental Science and Engineering, Inc	Full-scale operation of Central Area extraction system	Flow rates Groundwater levels Analytical; data
1996-1998, Radian International	Operation, maintenance, and optimization of North Balloon, Central Area, and South Balloon groundwater treatment systems	Flow rates Groundwater levels Analytical data Control system input/output
1998-1999, Tetra Tech, Inc.	Operation and maintenance, North Balloon, Central Area, and South Balloon groundwater treatment systems	Flow rates Analytical data Groundwater levels Control system input/output

Abbreviations:

DDJC Defense Distribution Depot San Joaquin, California
DNAPL Dense, non-aqueous phase liquid
IRP Installation Restoration Program
NPDES National Pollutant Discharge Elimination System
RI/FS remedial investigation/feasibility study
TPH total petroleum hydrocarbon compounds
UST underground storage tank
VOC volatile organic compound

Source: Radian 1999f.

and transported to an approved offsite landfill. Soil treatment using active soil-vapor extraction (SVE) is currently being applied to remediate VOCs in soils at the Central (Site P-6A) and South Balloon (Sites P-1E, P-1A, P-1B, and P-1C) Areas. In addition, soils contaminated with the pesticides 4,4'-Dichlorodiphenyltrichloroethane (DDT) and chlordane were excavated from the North Balloon Area and disposed off-site at a licensed facility. That action, documented in a Removal Action Memorandum, was completed in March 1995 (Table 1.1). The status of all currently-active sites at DDJC-Sharpe, listed with the Installation Restoration Program (IRP), is provided in Table 1.3.

During its operational history, over 60 USTs were installed and maintained at DDJC-Sharpe for various purposes (ESE, 1990). Most of the tanks were used for storage of petroleum fuels; however, a total of 27 non-fuel USTs were identified during the initial phases of the RI conducted at DDJC-Sharpe. Closure of these tank sites is overseen by the State program that manages closure of USTs. To date, nearly all of the petroleum-fuel USTs have been removed and closed (Table 1.3); and 22 of the non-fuel tanks have also been closed. Additional remediation work also is planned under DDJC-Sharpe's stormwater management program. Sludge containing high levels of metals and VOCs will be removed from a sump, and metals-contaminated sludge will be removed from an oxidation/evaporation pond. The sump and pond will then be closed.

The active remedial systems installed to address soil contamination (SVE systems) and the dissolved-contaminant groundwater plumes (groundwater pump-and-treat systems) are the focus of this RPO Phase II evaluation.

TABLE 1.3
STATUS OF IRP SITES AT DDJC-SHARPE
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

DSERTS	SWMU	Affected Media	Site Description	Status
Operable Unit 1 (OU1)				
1	P-1	Groundwater	Groundwater Plume - South Balloon	Remedial action in progress
2	P-2	Groundwater	Groundwater Plume - South Balloon	Remedial action in progress
3	P-3	Groundwater	Groundwater Plume - South Balloon	Remedial action in progress
4	P-4	Groundwater	Groundwater Plume - Central Area	Remedial action in progress
5	P-5	Groundwater	Groundwater Plume – Central Area	Remedial action in progress
6	P-6	Groundwater	Groundwater Plume - North Balloon	Remedial action in progress
7	P-7	Groundwater	Groundwater Plume - North Balloon	Remedial action in progress
8	P-8	Groundwater	Groundwater Plume - North Balloon	Remedial action in progress
Operable Unit 2 (OU2)				
21	S-13 (P6A)	Soil	VOC/SVE site	Remedial action in progress
36	S-28 (P 1A,B,C)	Soil	IWTP sludge disposal (VOC/SVE site)	Remedial action in progress
50	S-404	Soil	UST 46	Remedial Design
52	P-1E	Soil	VOC/SVE site	Remedial action in progress
84	S-186	Soil	UST 16; Oil/Water Separator	Remedial Design
136	S-108	Soil	UST 12	Remedial Design
137	S-42	Soil	UST 5	Remedial Design
138	S-116	Soil	UST 15	Remedial Design
139	S-119	Soil	UST 17	Remedial Design
140	S-118	Soil	UST 18/18A	Remedial Design
141	S-308	Soil	UST 34	Remedial Design
142	S-508	Soil	UST 73	Remedial Design
143	S-649(S)	Soil	UST 49	Remedial Design
144	S-649(N)	Soil	UST 55	Complete
145	P-8A	Soil	VOC/SVE site	Remedial action in progress
146	Bldg 199	Soil	POL	Remedial Design
147	Bldg 613	Soil	ORC™ pilot study	Remedial Design
148	Bldg 271	Soil	POL	Remedial Design

TABLE 1.3 (Continued)
STATUS OF IRP SITES AT DDJC-SHARPE
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

DSERTS	SWMU	Affected Media	Site Description	Status
149	S-135	Soil	UST 21	Remedial Design
150	S-371	Soil	UST Sites 38-44, 78, 88	Remedial Design
152	N-199	Soil	POL	Remedial action in progress

Abbreviations:

DSERTS Defense Sites Environmental Restoration Tracking System
IRP Installation Restoration Program
IWTP industrial wastewater treatment plant
ORC™ Oxygen Release Compound
POL petroleum fuels, oils, and lubricants handling/storage facility
SVE soil-vapor extraction
SWMU Solid Waste Management Unit
UST underground storage tank
VOC volatile organic compound

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SECTION 2
REVIEW OF CONCEPTUAL SITE MODEL

The conceptual hydrogeologic model of a site is a comprehensive description of the groundwater and surface-water systems at the site, the relationships among the systems, and their temporal evolution. The conceptual site model (CSM) provides the basis for understanding the occurrence and movement of water and contaminants at the site, and incorporates the geologic and hydrologic information necessary to guide site investigations and subsequent remediation activities. Without an adequate conceptual understanding of the hydrogeologic framework and the relationships among the various components of the hydrologic system, subsequent activities will not generate interpretations or conclusions that can be used with any confidence. In general, the conceptual hydrogeologic model incorporates the following components:

- A description of the general regional and local geology, including lithology, stratigraphy, and structure;
- Identification of principal hydrogeologic units, including specific water-bearing units and discrete zones or areas of relatively higher or lower hydraulic conductivity;
- Values for the hydraulic properties of the various hydrogeologic units, including hydraulic conductivity, specific yield, and specific storage; and if thicknesses of hydrostratigraphic units are known, their bulk properties of transmissivity and storativity;
- The elevation and configuration of the groundwater potentiometric surface(s);

- 1 • Surface drainage configuration, the capacities of streams, and gaining or losing
2 reaches;
- 3 • Hydrologic boundaries, including streams, drainage divides, and hydrogeologic
4 contacts with materials of lower or higher permeability; and
- 5 • Source(s) of contaminants, and the direction(s) and rate(s) of contaminant
6 migration.

7 The principal components of the CSM for DDJC-Sharpe were initially developed and
8 presented in the RI/FS (ESE, 1990). Over time, as additional investigations and
9 evaluations have been completed at the installation, interpretations of the various
10 components of the CSM have been modified and updated (Engineering Technologies
11 Associates, Inc. [ETA], 1993; Radian, 1999a; U.S. Army Corps of Engineers [USACE],
12 2000). Presumably, these interpretations provided the framework within which the
13 current remediation systems were conceived and designed, and also represent the
14 framework within which system performance should be evaluated. Examination and, if
15 necessary, refinement of the CSM therefore is an important element of the RPO
16 evaluation.

17 Parsons reviewed existing documents (ESE, 1990; ETA, 1993; Radian, 1999a; *ibid.*,
18 1999g; USACE, 2000) to assess the completeness and validity of the current CSM for
19 DDJC-Sharpe. Based on this review, it was apparent that existing discussions of the
20 CSM were not sufficiently detailed or comprehensive to meet the objectives of this RPO
21 evaluation. Therefore, the existing CSM was refined, in order to incorporate the most
22 current information available, and to resolve discrepancies in earlier interpretations. In
23 addition, field data were collected as part of the RPO evaluation, in order to evaluate the
24 possible occurrence of natural attenuation of contaminants in groundwater at DDJC-
25 Sharpe, and to identify the mechanisms of natural attenuation that might be active. This
26 information was used to develop a more complete understanding of the fate and
27 movement of contaminants in groundwater at the facility, and to assess the feasibility of
28 implementing monitored natural attenuation as an alternative remedial measure for
29 contaminants in groundwater.

1 A block diagram of the CSM, incorporating the primary features of DDJC-Sharpe,
2 was developed to serve as a visual aid for discussions in the following sections (Figure
3 2.1). This figure illustrates in three dimensions the relationships among the general
4 hydrogeologic features of the facility, the potential contaminant source areas, and the
5 extent of the dissolved contaminant plumes.

6 **2.1 DATA SOURCES**

7 The data sources that were reviewed for the purposes of evaluating the CSM included
8 the historical database (Section 2.1.1); a Natural Attenuation Study initiated by Radian
9 (1999a) (Section 2.1.2); and the results of additional field investigations completed by
10 Parsons in the summer of 2000 to further assess the potential for natural attenuation
11 (Section 2.1.3).

12 **2.1.1 Historical Database**

13 Historical water quality and water level data from 1992 to present was made available
14 in electronic format to Parsons for this RPO evaluation. Information collected prior to
15 1992 was available to a limited extent, in the form of time-series plots of chemical
16 concentrations, in documents that were produced from the early 1980s (ESE, 1990)
17 through 1990 (Radian 1999a). Chemical concentration data generated prior to 1992 were
18 compared with more recent information to gain a better understanding of the temporal
19 changes in extent and configuration of the dissolved contaminant plumes in groundwater,
20 and of the degree to which operation of remedial systems has influenced the
21 configuration and extent of the plumes.

22 **2.1.2 Monitored Natural Attenuation Study**

23 A preliminary, screening-level assessment of the potential applicability of natural
24 attenuation as a remedial option for dissolved solvent constituents in groundwater was
25 initiated by Radian in 1999 (Radian, 1999b). Parsons received and reviewed preliminary
26 data collected as part of this study (transmitted electronically on October 27, 2000 by Mr.
27 Michael Thomas at URS-Greiner Corporation [formerly Radian]). The data consisted of
28 the results of analyses of groundwater samples, collected from seven monitoring wells in
29 the North Balloon area, for VOCs and several natural attenuation parameters, including

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2 **Figure 2.1 Conceptual Site Model**

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1 dissolved oxygen (DO), pH, reduction/oxidation (redox) potential, temperature, chloride,
2 nitrate, sulfate, sulfide, alkalinity, manganese, ferrous iron, total organic carbon (TOC),
3 and methane. The wells sampled for the natural attenuation study were selected to
4 include locations upgradient of the contaminant plume; in suspected source areas; within
5 the plume; and at locations cross-gradient and downgradient of the plume. These data
6 were reviewed in conjunction with the evaluation of natural attenuation potential for
7 groundwater at the facility (discussed in Section 2.3.3).

8 **2.1.3 RPO Field Evaluation**

9 In order to supplement existing information, Parsons collected samples from two
10 subsets of wells that were being sampled during the sampling event conducted by Radian
11 in June and July, 2000. One subset of wells was selected for sampling and analysis of
12 several inorganic constituents and other parameters to assist in evaluating the potential
13 application of remediation by natural attenuation for VOCs in groundwater. A subset of
14 these wells was selected for sampling of arsenic (III) and (V) to evaluate the occurrence
15 and distribution of arsenic in groundwater and to assess possible alternative methods of
16 disposal of treated water from the A zone in the Central Area. Table 2.1 lists the wells
17 sampled, the analytes, and the analytical methods. A total of 42 wells located in the
18 South Balloon, Central, and North Balloon areas were sampled in conjunction with this
19 field effort. The sampling and analysis plan (SAP) for the collection of this additional
20 data was presented in the RPO Work Plan for DDJC-Sharpe (Parsons, 2000); the results
21 of the field evaluation are discussed in Section 2.5.

22 **2.2 ENVIRONMENTAL SETTING**

23 **2.2.1 Physiography, Regional Geology, and Hydrology**

24 DDJC-Sharpe is located in the San Joaquin Valley, in the southern part of the Great
25 Central Valley physiographic province, which extends 120 miles north of Sacramento to
26 Redding, and about 400 miles south to Bakersfield. The valley is drained by two large
27 river systems: the Sacramento River drains the northern part (north of the confluence of
28 the Sacramento and San Joaquin Rivers), and the San Joaquin River drains most of the
29 southern part. The two rivers join in a delta about 30 miles east of San Francisco and

TABLE 2.1
SAMPLES AND ANALYSES FOR EVENT OF JULY-AUGUST 2000
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Sample Location	Field Measurements										Laboratory Analyses					
	pH	ORP ^{a/}	Temperature	DO ^{b/}	Conductivity	Turbidity	Alkalinity	Sulfate	Ferrous		Chloride	Total Organic Carbon		Dissolved Organic Carbon		Arsenic III, V
									Iron	Manganese		(TOC)	(DOC)	VOCs ^{c,d/}	Nitrate	
	E150.1/SW9050 (direct-reading meter)	A2580B (direct-reading meter)	E170.1 (direct-reading meter)	Dissolved oxygen meter	E120.1/SW9050 (direct-reading meter)	A2580B (direct-reading meter)	Colorimetric (Hach 8221)	Colorimetric (Hach 8051)	Colorimetric (Hach 8146)	Colorimetric (Hach 8034)	USEPA Method 300	USEPA Method 415.1	USEPA Method 415.1	USEPA Method SW8260B	USEPA Method 300.0	Brooks-Rand SOP BR-0021
Sample Locations in North Balloon Area																
MW413A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW413B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW421A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW421B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW438A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW456B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW464C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW477A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW484A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW514B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW517A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW521B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW522C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Sample Locations in Central Area																
MW417A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW417B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW419B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW423A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW437B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW443A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW446A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW452A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW460C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW507A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW507C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW510C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW524A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Influent lines to Central Area treatment plant	✓	✓	✓	✓	✓	✓								✓		
Between stripping towers at Central Area treatment plant	✓	✓	✓	✓	✓	✓								✓		
Sample Locations in South Balloon Area																
DW001	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
DW003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW402C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW403A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW406A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW407A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW408A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW418B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW418C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW422A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW427C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW429A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW440A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW440B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW441B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW441C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW445C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW476A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
MW501A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW501B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
MW530B (well destroyed)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Influent lines to South Balloon treatment plant	✓	✓	✓	✓	✓	✓								✓		
Between stripping towers at South Balloon treatment plant	✓	✓	✓	✓	✓	✓								✓		

^{a/} ORP = oxidation reduction potential.

^{b/} DO = dissolved oxygen.

^{a/} VOC = volatile organic compound.

^{b/} VOC samples are generally collected as part of the regular monitoring program. Therefore, groundwater samples from wells were not analyzed for VOCs as part of this program to avoid duplication of effort.

1 thence flow to the Pacific Ocean through the San Francisco Bay estuary (Figure 1.1).
2 The valley is approximately 40 miles wide, and is bordered by the Sierra Nevada range
3 on the east, and the mountains of the Coast Ranges on the west (Norris and Webb, 1990).

4 The DDJC-Sharpe facility is about 2 miles east of the San Joaquin River, on an
5 alluvial plain forming the eastern side of the San Joaquin Valley. The plain is nearly flat,
6 and is dissected by numerous westerly-trending streams that drain the Sierra Nevada.
7 Land surface at the facility is flat to gently sloping (from east to west), and exhibits little
8 topographic relief. Elevations range from about 20 feet above mean sea level (amsl) on
9 the eastern side of the facility, to approximately 15 feet amsl on the western side (ESE,
10 1990).

11 The Central Valley is actually an elongate, north-south-trending basin, that has been
12 downwarped and filled with material eroded from the surrounding mountains since pre-
13 Cretaceous time (ESE, 1990). Deposits in the central part of the valley comprise a
14 thickness of thousands of feet of consolidated and unconsolidated alluvial sediments
15 derived from the surrounding mountains, together with recent deposits of the San Joaquin
16 River. Alluvial fans, extending from the mountain fronts toward the axis of the valley,
17 have formed on both sides of the Central Valley. The deposits of individual fans may
18 coalesce, or may be separated by inter-fan deposits. Alluvial-fan deposits are a common
19 feature of arid climates and are formed by the rapid deposition of sediments transported
20 by intermittently-occurring fluvial and debris-flow processes, including deposition by
21 ephemeral streams, and flash flooding. The interfan deposits are typically areally
22 extensive and contain more fine-grained material (fine sand, silt, and clay) than the
23 alluvial-fan deposits. In this depositional setting, fine-grained detritus is carried farther
24 toward the axis of the valley (nearer to the rivers), leaving the coarse-grained material
25 closer to the valley margins. Over time, shifts in the courses of ephemeral stream
26 channels cause the fans to coalesce, forming broad sheets of interfingering, wedge-
27 shaped lenses of gravel, sand, and finer detritus (Back *et al.*, 1988).

28 The principal source of fresh groundwater throughout the Central Valley is within the
29 upper 1,000 feet of sedimentary deposits. Brackish or saline water occurs at depth below

1 the freshwater zone (Figure 2.2). As a consequence of the heterogeneous nature of
2 geologic units within the Central Valley, there is considerable spatial variation in the
3 hydraulic properties of the water-bearing zones. The most productive water-bearing
4 zones occur within coarse-grained deposits of alluvial origin.

5 Fresh groundwater occurs under confined and unconfined conditions in the Central
6 Valley. Prior to development of the groundwater resource, groundwater movement was
7 generally from the mountains bordering the valley, towards its axis. Large-scale
8 development of groundwater (primarily for irrigation purposes) has modified the natural
9 flow patterns by creating depressions in the groundwater potentiometric surface
10 surrounding the major extraction wellfields. More recently, importation of surface water
11 has, to some extent, mitigated the effects of these anthropogenically-induced changes by
12 causing reduction in the demand for groundwater, and also by increasing the amount of
13 recharge to the groundwater system (Back *et al.*, 1988)

14 **2.2.2 Climate**

15 The climate in the Central Valley is characterized by dry, hot summers and wet, mild
16 winters (Radian, 1999a). Summer temperatures range from 60 to 100 degrees Fahrenheit
17 (°F) and winter temperatures range from 30°F to 50°F. Most precipitation occurs from
18 December through April, and rainfall averages 14 inches per year. In wetter years, as
19 much as 30 inches of rain may fall; whereas total precipitation in dry years may be less
20 than 5 inches. Additional information regarding climatic conditions of the Central Valley
21 (including the DDJC-Sharpe facility) is presented by ESE (1990) and Radian (1999a).

22 **2.2.3 Facility Setting**

23 **2.2.3.1 Surface-Water Hydrology**

24 Most surface water runoff at the installation is collected by a storm-water drainage
25 system. The storm-water system discharges to the South San Joaquin Irrigation District
26 Canal (SSJIDC), which parallels the eastern boundary of the installation (Figure 1.2), and
27 drains to the north into French Camp Slough, a tributary of the San Joaquin River. Along
28 the western boundary of the installation, storm water drains to dry wells, and is allowed
29 to percolate into the vadose zone.

1

2 **Figure 2.2 Schematic Regional Hydrogeologic Cross-Section**

3

2.2.3.2 Geology

Soils at land surface at DDJC-Sharpe consist of loam to sandy loam that have been disturbed by past agricultural activities, and subsequent industrial development. Beneath the soils in the shallow subsurface, a “hardpan”, or caliche layer commonly is present (Radian 1999a).

The principal geologic units underlying the DDJC-Sharpe facility are the Victor and Laguna Formations, which are Tertiary in age. Where present, the Victor Formation extends from ground surface to a depth of approximately 60 feet below ground surface (bgs); however, the thickness of the unit is reported to be variable beneath the facility, and the formation may be absent at some locations (ESE, 1990). Deposits of the Victor Formation consist of discontinuous strata and lenses of unconsolidated gravel, sand, silt, and clay. These sediments originated as erosional detritus of the Sierra Nevada to the east, and were deposited in alluvial fans and interfan areas (Radian 1999a). Locally, the Victor Formation was incised in Recent time by stream channels of the San Joaquin River, and these inactive “paleochannels” have since been filled with fluvial deposits, consisting of poorly-sorted, unconsolidated gravel, sand, and silt.

Where present, the Victor Formation overlies the irregular upper surface of the Laguna Formation (Figure 2.3). The deposits of the Laguna Formation consist of fluvial deposits of sand and silt, in discontinuous and irregular strata and lenses, with lesser amounts of clay and gravel. The Laguna Formation probably ranges in thickness from about 430 to over 1,000 feet (ESE, 1990). These deposits are similar to the overlying Victor Formation, but are partly consolidated, and tend to contain more fine-grained sand and silt. Within the Laguna Formation, a clay layer, generally greater than 20 feet in thickness, is present in the depth interval between 220 and 280 feet bgs. Thin, interbedded sand and clay strata also may be present in this interval. This clayey stratum may be stratigraphically equivalent to the Corcoran Clay that occurs throughout the San Joaquin Valley (Figure 2.2), but is generally thinner than is typical of the Corcoran Clay (Radian, 1999a).

1

2 **Figure 2.3 Generalized Stratigraphic Column**

3

1 The contact between the Victor and Laguna Formations is probably at a depth ranging
2 from 0 to about 60 feet bgs beneath the facility. As a consequence of the similarities in
3 lithology and stratigraphy between the two units, the Laguna and Victor Formations are
4 generally indistinguishable in the vicinity of DDJC-Sharpe, and the contact is difficult to
5 identify (ESE, 1990).

6 **2.2.3.3 Hydrostratigraphy**

7 The water-bearing unit underlying DDJC-Sharpe is heterogeneous, as a direct result of
8 the complexity and spatial variability of the depositional processes that originally laid
9 down the sediments comprising the subsurface. Hydrostratigraphically, the uppermost
10 water-bearing unit extends from the surface of the water table at a depth of approximately
11 14 feet bgs, to the top of the clay stratum in the depth interval from 220 to 280 feet bgs,
12 and consists of relatively permeable zones consisting of sandy (occasionally gravelly)
13 layers 5 to 12 feet thick, interbedded with lower permeability silt and clay strata. The
14 more permeable sandy intervals comprise approximately twenty-five percent of the
15 subsurface materials, and finer-grained, silty to clayey intervals comprise the remaining
16 75 percent (ESE, 1990). Groundwater is present under unconfined conditions in the more
17 transmissive intervals in the upper part of the water-bearing unit; however, due to the
18 abundance of silt and clay layers of lower permeability, semi-confined conditions likely
19 exist at depth.

20 In examining the configuration of the water-bearing unit, relatively permeable, sandy
21 strata could not be correlated laterally between boreholes across the facility, even though
22 detailed and comprehensive evaluations of subsurface conditions, including construction
23 of detailed cross-sections, have been completed by others (ESE, 1990; Radian, 1999a;
24 *ibid.*, 1999g). As a result of the braided and intercalated nature of alluvial-fan deposits, it
25 is likely that vertically-juxtaposed coarse-grained (sandy to gravelly) strata are
26 interconnected, perhaps on a scale smaller than can be readily observed in the field. In
27 contrast, some clay strata appear to extend laterally for distances up to several thousand
28 feet (e.g., a stratum at a depth of 110 feet bgs in the Central and North Balloon areas);
29 however, most of the clay layers are discontinuous, and often pinch out between
30 boreholes (Radian 1999a).

Four principal “aquifer zones” or “monitoring zones”, referred to as the “A”, “B”, “C”, and “D” zones (with “A” being the uppermost zone and “D” being the deepest) have been distinguished in the upper 270 feet of the hydrogeologic system (Figure 2.3) (ESE, 1990; Radian, 1999a). Each of the zones includes sandy strata ranging from 5 to 12 feet in thickness. The depth intervals corresponding to each monitoring zone, as established by Radian (1999a) on the basis of relatively current hydrogeologic information, are as follow:

- “A” Zone, extending from the water table to a depth of 40 feet bgs;
- “B” Zone, in the depth interval of 40 to 90 feet bgs;
- “C” Zone, in the depth interval of 90 to 170 feet bgs;
- “D” Zone, in the depth interval of 170 to 270 feet bgs (i.e., to the top of the Corcoran Clay).

Use of the term “monitoring zone” rather than “aquifer zone” is preferred, because the four zones do not appear to be distinguishable on the basis of their hydrogeologic characteristics (e.g., lithology, hydraulic properties, etc.), and do not appear to be separated hydraulically by low-permeability barriers. Furthermore, hydrologic observations, including migration of contaminants between different monitoring zones at some locations (Section 2.3.2.2), and the propagation of hydraulic stresses through several monitoring zones during pumping tests (as summarized by ESE [1990]), indicate that the monitoring zones are generally in hydraulic communication. Therefore, the complex hydrostratigraphic package of gravel, sand, silt, and clay that extends to a depth of approximately 270 feet bgs comprises a single, heterogeneous water-bearing unit.

2.2.3.4 Groundwater Elevations, Gradients, and Flow Directions

Groundwater in the “A” zone at DDJC-Sharpe (the “water table” or “potentiometric surface”) is typically encountered at depths ranging from 10 to 20 ft bgs, depending upon location on the installation. Regionally, the direction of groundwater movement is generally from east to west, toward the San Joaquin River. Historically, groundwater

1 movement in the vicinity of DDJC-Sharpe has been from the east or southeast to the
2 northwest, as a result of the hydraulic influence of nearby irrigation wells located north
3 and northwest of the facility (ESE, 1990). The completion intervals of these wells (the
4 zones from which the wells withdraw groundwater) are reported to be anywhere from 61
5 to 270 feet bgs; however, most of the irrigation wells produce water from the deeper part
6 of the water-bearing unit, at depths ranging from 200 to 270 feet bgs. Three potable
7 wells servicing DDJC-Sharpe, and Lathrop City Well No. 5 (located near the South
8 Balloon area) also may have influenced groundwater flow directions, but on a more
9 localized scale.

10 The historic hydraulic gradient in the vicinity of DDJC-Sharpe, prior to installation
11 and operation of groundwater extraction systems on the facility, is estimated to be about
12 0.002 feet per foot (ft/ft) to the northwest (ESE, 1990), based on hydraulic potentiometric
13 measurements collected prior to 1987 (before remedial activities were initiated). Since
14 the commencement of remedial activities in 1987, extraction wells, injection wells, and
15 percolation ponds have been placed in service (Table 2.2). These all are capable of
16 influencing conditions in the groundwater system, including the configuration of the
17 potentiometric surface, local hydraulic gradients, depth to the water table, and recharge to
18 the groundwater system. In particular, the configuration of the potentiometric surface
19 (and, therefore, the local directions of groundwater movement) have been modified
20 significantly as a consequence of long-term operation of the groundwater extraction
21 systems comprising part of the existing remedial systems at DDJC-Sharpe (Figures 2.4,
22 2.5, and 2.6). The configuration and operation of the groundwater ETI systems are
23 discussed in greater detail in Section 4.

24 A vertical hydraulic gradient oriented in the downward direction is generally present
25 in the groundwater system in the vicinity of DDJC-Sharpe, although the direction and
26 magnitude of vertical gradients have been temporally variable through the pre-

1

2 **Figure 2.4 Groundwater Potentiometric Contours in “A” Zone, July 7 – 9, 1999**

3

1 **Figure 2.5 Groundwater Potentiometric Contours in “B” Zone, July 7 – 9, 1999**

2

1 **Figure 2.6 Groundwater Potentiometric Contours in “C” Zone, July 7 – 9, 1999**

2

TABLE 2.2
FEATURES OF GROUNDWATER ETI^{a/} SYSTEMS
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Monitoring Zone	Area		
	North Balloon	Central Area	South Balloon
“A” Zone	10 extraction wells pumping 85 gpm ^{b/} total	2 extraction wells pumping 20 gpm total; 2 injection wells; 2 percolation ponds	11 extraction wells pumping 42 gpm total
“B” Zone	5 extraction wells pumping 50 gpm total	3 extraction wells ^{c/} pumping 113 gpm total; 1 injection well	4 extraction wells pumping 28 gpm total
“C” Zone	3 extraction wells pumping 118 gpm total	4 extraction wells pumping 334 gpm total	3 extraction wells pumping 99 gpm total
“D” Zone	None	None	None

^{a/} ETI = extraction, treatment, and disposal (infiltration, injection, or other discharge).

^{b/} gpm = gallons per minute.

^{c/} Extraction wells EWCAB1 and EWCAB2 are not considered Zone “B” extraction wells because the completion intervals of these wells are within or near the contact between the A and B zones. Wells EWCAB1 and EWCAB2 are therefore considered to be Zone “A” extraction wells.

remediation period (1984 to 1987) to the present. Downward gradients are most likely to be observed during the summer months (May to August) when nearby, large-capacity irrigation wells are in operation and precipitation is the lowest (ESE, 1990). A conceptual cross-section displaying directions of groundwater movement resulting from the downward vertical gradient in the groundwater system beneath the South Balloon area (third quarter 1999) is presented in Figure 2.7. During the winter months when irrigation requirements (and consequently, groundwater extraction rates) are lower, an upward hydraulic gradient can occur (e.g., November 1984 [ESE, 1990]). Downward-oriented vertical gradients also may be induced at some locations by relatively high rates of groundwater extraction by remediation-system extraction wells, completed in the “C” zone (for example, well EWC3, Figure 4.7). Downward movement of groundwater resulting from pumping in the “C” zone may be contributing to the migration of contaminants in groundwater from shallow to deeper zones beneath DDJC-Sharpe.

1

2 **Figure 2.7 Hydrogeologic Cross-Section A-A', South Balloon Area**

3

2.2.3.5 Hydraulic Conductivity and Velocity of Groundwater Movement

The hydraulic properties of the earth materials in the water-bearing unit at DDJC-Sharpe have been evaluated on several occasions. ESE (1990) summarized the results of pumping tests that were conducted in several monitoring zones of the water-bearing unit. Evaluation of the results of these tests enabled estimates to be generated of the values of transmissivity (the capacity of the water-bearing unit at DDJC-Sharpe to transmit water) and storativity (the capacity of the water-bearing unit to store water). “*Transmissivity*” is generally regarded (c.f., Freeze and Cherry, 1979) as the product of the value of hydraulic conductivity (K_h) of the saturated earth materials comprising a water-bearing unit, and the saturated thickness of the unit:

$$T = K_h \times t_{saturated} \quad \text{Equation 2-1}$$

where

T = transmissivity of the water-bearing unit (square feet per day [ft²/day]);
 K_h = horizontal hydraulic conductivity of the water-bearing unit (feet per day [ft/day]); and
 $t_{saturated}$ = saturated thickness of water-bearing unit (ft).

Note that the value for hydraulic conductivity of a water-bearing unit can be estimated from the value of transmissivity calculated for the unit from the results of aquifer testing, if Equation 2-1 is re-arranged, and the value of transmissivity is divided by the saturated thickness of the unit.

The ranges of estimates of transmissivity resulting from analyses of aquifer tests at DDJC-Sharpe are presented in Table 2.3, together with values of hydraulic conductivity (K) estimated using Equation 2-1 with the values of transmissivity and representative thicknesses of the zones. The results presented in Table 2.3 are considered to be approximate values, because the conditions of the aquifer tests (as reported by ESE [1990] did not meet several critical assumptions necessary for analyses of aquifer tests (e.g., significant leakage from adjacent zones occurred during the tests; pumping wells and monitoring wells are partially penetrating) (Kruseman and deRidder, 1994.).

TABLE 2.3
VALUES OF TRANSMISSIVITY AND HYDRAULIC CONDUCTIVITY
ESTIMATED FROM RESULTS OF AQUIFER TESTS
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Monitoring Zone	Transmissivity (ft ² /day) ^{a/}			Average ^{b/} Thickness of Zone (ft) ^{c/}	Estimated Hydraulic Conductivity ^{d/} (ft/day) ^{e/}
	Range in North Balloon Area	Range in South Balloon Area	Facility Average		
“A” Zone	79 – 920	-- ^{f/}	500	25	20
“B” Zone	290	46 - 800	360	50	7
“C” Zone	1,300 - 3,500	190 - 8,700	3,400	80	43
“D” Zone	--	4,500 - 7,000	5,800	100	58

^{a/} ft²/day = square feet per day.

^{b/} “Average” thickness of monitoring zone is the arithmetic average reported for DDJC-Sharpe (ESE, 1990).

^{c/} ft = feet.

^{d/} “Hydraulic conductivity” is the quotient of transmissivity (Column 4) divided by thickness of the transmissive unit (Column 5) (Equation 2-1).

^{e/} ft/day = feet per day.

^{f/} A dash (--) indicates that information regarding hydraulic properties in this unit is not available.

Based on the information presented in Table 2.3, the hydraulic conductivity values of the earth materials comprising the “A” and “B” monitoring zones are significantly lower than those of the “C” and “D” zones (the “A” and “B” zones are *less permeable*). This is supported by the observation that the production rates of extraction wells completed in the “C” zone are higher than the production rates of extraction wells completed in the “A” or “B” zones (compare well production rates in Table 2.2).

In addition to the pumping tests completed in the field, several permeability tests were conducted in the laboratory, using representative soils from DDJC-Sharpe (ESE, 1990, Table 5.3.2). The hydraulic conductivity value resulting from one laboratory permeability test for sand collected in the “A” zone was reported to be 0.003 centimeters per second (cm/sec), equivalent to a value of about 9 ft/day. This value is in relatively good agreement with the hydraulic conductivity estimated from the results of pumping tests of wells completed in “A” zone sands (Table 2.3). Values for hydraulic conductivity of finer-grained materials, estimated from the results of laboratory

1 permeability tests, were much lower. Two tests performed on silts collected from the
2 unsaturated zone generated estimates of hydraulic conductivity values of 0.00003 cm/sec
3 and 0.000007 cm/sec. A single lab test completed using a sample of clay collected from
4 the upper part of the “B” zone generated an estimated hydraulic conductivity value of
5 0.00000001 cm/sec (ESE, 1990).

6 The velocity of groundwater movement through a saturated medium (the “*particle*
7 *velocity*”, or average linear velocity that a molecule of groundwater would attain) can be
8 estimated using a modification of Darcy’s Law (Freeze and Cherry, 1979):

$$V_h = \frac{K_h \times dh/dl}{n_e} \quad \text{Equation 2-2}$$

10 where

- 11 V_h = horizontal velocity of groundwater movement (ft/day);
12 dh/dl = horizontal hydraulic gradient in water-bearing unit (ft/ft); and
13 n_e = effective porosity of earth materials in the water-bearing unit ().

14 The historical groundwater gradient in the “A” and “B” zones, including the effects of
15 increases in hydraulic gradient resulting from seasonal pumping of agricultural wells, is
16 about 0.002 ft/ft (Section 2.2.3.4); and the average hydraulic conductivity of materials in
17 the “A” and “B” zones (considered together) is about 14 ft/day (Table 2.3). Using these
18 values, together with an approximate value of 0.206 for effective porosity (Appendix B),
19 the average linear velocity of groundwater movement in the “A” and “B” zones is
20 estimated to be about 0.14 ft/day (equivalent to about 50 feet per year [ft/yr]). The
21 average linear velocity of groundwater movement in the “C” zone is somewhat greater
22 (about 0.42 ft/d [equivalent to 160 ft/yr]), as a consequence of the greater average
23 hydraulic conductivity of earth materials in the “C” zone (about 43 ft/day; Table 2.3).
24 Although the different zones are generally in hydraulic communication and together
25 comprise a single water-bearing unit, the differences in hydraulic properties and resulting
26 groundwater velocities provides an indication of the heterogeneities in the earth materials
27 throughout the water-bearing unit.

2.3 NATURE AND EXTENT OF CONTAMINANTS IN SOIL AND GROUNDWATER

During the course of IRP investigations spanning a period of nearly 20 years, various constituents, including VOCs and SVOCs, fuel hydrocarbons, pesticides, polychlorinated biphenyl compounds (PCBs), inorganic constituents, and several metals have been detected in soil and groundwater samples collected at DDJC-Sharpe. The constituents that have been detected at concentrations sufficiently elevated to be considered COCs in soils are chromium, lead, and VOCs (Section 1.4.2); and the COCs in groundwater are VOCs, bromacil, arsenic, nitrate, and selenium. TCE is the VOC that has been detected most frequently, and at the highest concentrations, in soil and groundwater samples at DDJC-Sharpe. Other volatile constituents have been detected at lesser frequencies and lower concentrations. The results of previous soil and groundwater investigations are summarized in the following sections.

2.3.1 Contaminants in Soil

The base-wide ROD (also referred to as the OU2 ROD) was intended to address the requirements for comprehensive cleanup of soil in the unsaturated zone, above the water-bearing unit containing the groundwater zone (ESE, 1996). The selected remedy identified in the ROD included removal and off-site disposal of soil contaminated with lead and chromium; on-site treatment of soils contaminated with VOCs using SVE; and declarations of NFA for 111 solid waste management units (SWMUs). The locations of currently-active SWMUs and other areas of soil contamination at DDJC-Sharpe are presented on Figure 2.8.

2.3.1.1 Lead and Chromium in Soils

Historic activities on the facility, including painting, metal stripping, and waste disposal, introduced chromium and lead to on-facility soils (Section 1.4.2). The ROD for OU2 (ESE, 1996) identified areas in the North Balloon and South Balloon where near-surface soils (at depths less than 2 feet bgs) contained lead or chromium at concentrations that exceeded the respective cleanup standards (1,000 milligrams per kilogram [mg/kg] for lead and 300 mg/kg for chromium). These areas include SWMU sites S-3 and S-26 in the North Balloon, and sites S-30, S-33/29, and S-36 in the South Balloon (Figure 2.8).

1

2 **Figure 2.8 Solid Waste Management Units and Other Areas of Soil Contamination**

3

1 Additional soil samples were collected from these sites in 1996, to confirm the
2 occurrence of lead and chromium at elevated concentrations, and to better evaluate the
3 vertical and lateral extent of lead and chromium in soils. Waste-extraction tests (WET
4 tests) were also performed on selected samples, to evaluate whether metals in the soils
5 were sufficiently soluble to be capable of migrating to groundwater (Radian, 1999d). In
6 addition, groundwater samples were collected beneath the sites, to assess the possible
7 vertical migration of metals from soil to groundwater.

8 Based on the results of the 1996 sampling event, the concentrations of lead and
9 chromium in soils at sites S-3 and S-26 in the North Balloon area exceeded cleanup
10 standards, but the concentrations of lead and chromium in soils at the three sites in the
11 South Balloon did not. No evidence of vertical migration of lead or chromium through
12 the soil to groundwater was identified at any of the sites. Soils at sites S-3 and S-26, in
13 which lead or chromium were present at concentrations in excess of cleanup standards,
14 were excavated and disposed at a licensed off-site facility in June 1998 (CKY Inc., 1998;
15 Radian, 1999d). These sites have been recommended for closure; regulatory concurrence
16 is pending.

17 Further investigation was conducted in 1997 at the South Balloon burn pits (Site S-
18 33/29) to address concerns of the Central Valley Regional Water Quality Control Board
19 (RWQCB) regarding possible groundwater contamination resulting from metals in the
20 vadose zone. During the investigation, chromium was detected in groundwater samples
21 collected from locations downgradient of the burn pits. Additional soil and groundwater
22 samples were collected as part of a post-ROD investigation at site S-33/29 in May 1998.
23 Later in 1999, additional soil samples were collected at Sites S-30 and S-36. Based on
24 the results of these investigations, NFA has been recommended at each of these sites;
25 regulatory approval of the recommendation is pending (Radian, 1999e).

26 **2.3.1.2 VOCs in Soil**

27 VOCs were introduced to soils on the facility during historic operation as a result of
28 historic use practices and waste disposal in designated areas in the South Balloon and
29 North Balloon, and in undesignated, isolated parts of the Central Area of the depot (ESE,

1 1996). Accidental releases of VOCs also occurred in areas where fueling or fuel removal
2 from vehicles and equipment occurred.

3 The occurrence of VOCs in soil within the vadose zone was intensively investigated
4 during the RI, using soil-vapor sampling techniques (ESE, 1990). Areas having elevated
5 concentrations of VOCs in soil vapor (greater than 500 parts per billion by volume [ppbv]
6 of TCE) were further investigated by drilling soil borings and collecting and analyzing
7 soil samples. Several areas were identified in which degradation of groundwater was
8 suspected to be a consequence of migration of VOCs through the soils in the unsaturated
9 zone to groundwater (ESE, 1990; *ibid.*, 1994a; *ibid.*, 1996) (Figure 2.8). The
10 concentrations of TCE in soil vapor at five sites – sites P-1A, P-1B, P-1C, and P-1E, in
11 the South Balloon area, and site P-6A, in the Central Area (Figure 2.8) -- exceeded the
12 cleanup standard of 350 ppbv of TCE, established in the ROD for OU2. On the basis of
13 subsequent soil-vapor sampling results (Radian, 1997a; *ibid.*, 1999e), the concentrations
14 of TCE in soil vapor at five sites -- sites P-1D, P-1F, P-4A, P-4C, and P-5A -- were
15 below cleanup standards; and these five sites therefore were recommended for NFA
16 (Radian, 1999e). An additional six sites (P-1G, P-2A, P-2B, P-3A, P-4B, and P-8A) also
17 were recommended for NFA on the basis of calculations of the migration potential of
18 VOCs in the unsaturated zone at these locations, which demonstrated that groundwater
19 beneath the sites would not be adversely affected by VOCs remaining in the unsaturated
20 zone. Regulatory concurrence with the NFA recommendations for these sites is pending
21 (Radian, 1999a).

22 **2.3.1.3 Other Contaminants in Soils**

23 Pesticides and petroleum hydrocarbon compounds have also been detected in soils at
24 DDJC-Sharpe (ESE, 1996). In December 1992, approximately 3,000 yd³ of soils
25 contaminated with petroleum-fuel constituents were excavated from the North Balloon
26 area and transported to a licensed off-site landfill. Soils in the North Balloon area that
27 contained elevated concentrations of pesticides (DDT and chlordane; Figure 2.8) were
28 excavated and disposed off-facility at a licensed landfill in March 1995. Closure of non-
29 fuel underground storage tanks has been deferred to a State program that manages closure
30 of USTs (ESE, 1996).

2.3.2 Contaminants in Groundwater

Groundwater sampling has been conducted at DDJC-Sharpe since investigations began in the early 1980s. Groundwater samples have been analyzed for VOCs, petroleum hydrocarbon compounds, SVOCs, pesticides/herbicides, nitrates, and dissolved metals (Radian, 1999a). Of these analytes, VOCs, bromacil, arsenic, selenium, and nitrate have been identified as the primary chemicals of concern (ESE, 1993a). VOCs are the most widespread contaminants in groundwater beneath DDJC-Sharpe, and adjacent, off-installation areas. TCE has been the VOC most frequently detected in groundwater, and has been detected at the highest concentrations. Potential sources of contaminants, and the nature and extent of the most frequently detected COCs in groundwater, are discussed in the following subsections. A discussion of those constituents less frequently detected in groundwater at DDJC-Sharpe was included in the FAA Annual Progress Report (Radian, 1999a).

2.3.2.1 Sources of Contaminants in Groundwater

Past use of chlorinated solvents and other chemicals, and/or disposal practices, probably resulted in the introduction of these constituents to soil in the subsurface at DDJC-Sharpe. Anthropogenic contaminants in groundwater beneath DDJC-Sharpe probably originated at contaminant source areas in vadose-zone soils, and subsequently migrated to groundwater via one of several mechanisms (Appendix B). Contaminants in groundwater, including VOCs, pesticides, and chromium, are immediately beneath, or downgradient from areas of known or suspected soil contamination (Section 2.3.1; Figure 2.8) (Radian, 1999a). Possible contaminant sources include areas where TCE has been detected in soil or soil vapor; several of the SWMUs (source of metals contamination); and the pesticide mix area. Contaminated soils in some areas have been excavated and removed from DDJC-Sharpe (Section 2.3.1); some sites are undergoing remediation using SVE; and other sites have been recommended for no further action.

Several other point and non-point sources of contaminants have been identified at DDJC-Sharpe (Radian, 1999a). The occasional detections of bromacil and pesticides (primarily heptachlor epoxide) in groundwater samples collected from the North Balloon area may be a result of historic pesticide mixing operations in the vicinity, or may be a

consequence of normal and intended use of pesticides and herbicides during the historic period of activities at DDJC-Sharpe. The sporadic detection of pesticides at low concentrations in groundwater of the Central Area has been attributed to normal and intended historic use of pesticides in that area. Bromacil detections in groundwater samples from wells near the eastern and western boundaries of DDJC-Sharpe have been attributed to bromacil application on nearby agricultural land, with subsequent percolation of bromacil through the vadose zone, or migration of bromacil in stormwater runoff to nearby dry wells. Nitrate may be present in groundwater because it is a principal constituent of fertilizers used on agricultural lands surrounding DDJC-Sharpe. Arsenic and selenium may be present in groundwater as naturally-occurring constituents, dissolved from the soil matrix; or could be present as constituents of pesticides or herbicides, stored and used at DDJC-Sharpe, that have subsequently migrated through the unsaturated zone to groundwater.

2.3.2.2 VOCs in Groundwater

VOCs were introduced to the subsurface at source areas in various locations on the DDJC-Sharpe installation (Section 2.3.2.1), apparently as a consequence of historic operations (Section 1.4). In addition to TCE, other VOCs including bromodichloromethane, carbon tetrachloride, 1,2-dichloropropane, 1,2-DCB, 1,4-DCB, 1,2-dichloroethane (1,2-DCA), 1,1-DCE, *cis*-1,2-DCE, *trans*-1,2-DCE, PCE, 1,1,1-TCA, 1,1,2-TCA, and vinyl chloride, have been detected in groundwater samples, although most of these constituents have been detected only sporadically, and at lower concentrations than TCE (Radian, 2000a). After moving from source areas through the vadose zone to the water table in the uppermost (“A” zone) parts of the groundwater system, contaminants have migrated in groundwater to areas downgradient of chemical sources, in accordance with the effects of several migration processes (Appendix B).

The results of early phases of remedial investigations at DDJC-Sharpe suggested that VOCs might be present in groundwater as seven or eight separate and distinct plumes, originating at different source areas (ESE, 1990). However, as additional information subsequently has been compiled, it is apparent that several of these plumes actually are co-mingled, so that there appears to be a single VOC plume originating in the South

1 Balloon area, two separate VOC plumes originating in the Central Area, and a single
2 VOC plume originating in the North Balloon area (Figure 2.1). As a consequence of the
3 downward-directed vertical hydraulic gradients that occur during much of the year,
4 VOCs in the plumes have migrated to increasingly greater depths in the water-bearing
5 unit with increasing migration distance from source areas.

6 Historically, VOCs (primarily TCE) have been detected in samples from monitoring
7 wells completed in the A-, B-, and C-monitoring zones, in the North Balloon, South
8 Balloon, and Central Area (Figures 2.9, 2.10, and 2.11, after Radian [1999g]). Based on
9 results from the third quarter 1999 monitoring event, the lateral extent of TCE in
10 groundwater appears to be the greatest in the B zone; and the highest concentrations of
11 TCE occur in groundwater within the B and C zones. Radian periodically evaluates
12 whether the concentrations of TCE in groundwater samples from a subset of wells in the
13 monitoring network display temporal trends (e.g., Radian, 1999g). In general, TCE
14 concentrations in groundwater samples from wells completed in the “A” zone display
15 decreasing trends through time (Figure 2.9). TCE concentrations in samples from wells
16 completed in the “B” and “C” zones may display decreasing or increasing temporal
17 trends (Figures 2.10 and 2.11).

18 To date, TCE has been detected only sporadically, and at low concentrations, in
19 groundwater samples from the “D” zone. During the third quarter 1999 monitoring
20 event, TCE was detected in the groundwater sample from only three of the 53 wells
21 completed in the “D” zone that were sampled for VOCs (Radian, 1999g). The three
22 wells in which TCE was detected are located in the North Balloon area. TCE was
23 detected in the samples from potable wells PW020 and PW03B, at concentrations of 0.6
24 µg/L and 0.7 µg/L, respectively; and was detected at a concentration of 6.5 µg/L in the
25 sample from monitoring well MW465CD which is actually screened in the deeper part of
26 the C zone (Figure 2.12, based on Radian, 1999g). Therefore, only limited migration of
27 TCE has occurred into deeper parts of the water-bearing unit; and in the few “D”-zone
28 wells having discernible temporal trends in concentrations, the concentrations of TCE
29 have been decreasing through time (Figure 2.12).

1

2 **Figure 2.9 TCE Concentrations in Groundwater in the “A” Zone – Third Quarter**
3 **1999**

4

- 1 **Figure 2.10 TCE Concentrations in Groundwater in the “B” Zone – Third Quarter**
- 2 **1999**
- 3

- 1 **Figure 2.11 TCE Concentrations in Groundwater in the “C” Zone – Third Quarter**
- 2 **1999**
- 3

- 1 **Figure 2.12 TCE Concentrations in Groundwater in the “D” Zone and Potable**
- 2 **Wells – Third Quarter 1999**
- 3

1 As previously discussed (Section 2.2.3.3), the “A”, “B”, “C”, and “D” monitoring
2 zones at DDJC-Sharpe are not distinct hydrostratigraphic units, but actually comprise
3 different depth intervals within the same, hydraulically-interconnected, water-bearing
4 unit. It is instructive to examine a more representative depiction of the lateral extent of
5 TCE in groundwater throughout the entire water-bearing unit, generated by considering
6 all of the results of a single monitoring event together (Figure 2.13), rather than grouping
7 the results by groundwater monitoring zone. The full lateral extent of TCE in
8 groundwater beneath DDJC-Sharpe in the third quarter 1999 (based on results reported
9 by Radian [1999g]) is indicated on Figure 2.13. The concentration of TCE, presented
10 thematically at each monitoring point indicated on Figure 2.13, is the highest
11 concentration detected in groundwater from an individual well within a well cluster at a
12 particular location, regardless of the depth interval from which the sample was collected.
13 For example, TCE was detected, at a concentration of 1.0 µg/L in the sample from well
14 MW508A, completed in the “A” zone west of the facility boundary in the southern part
15 of the Central Area (Figure 2.9). TCE was detected at a concentration of 20 µg/L in the
16 sample from well MW508B (the “B”-zone well of the cluster; Figure 2.10), and was not
17 detected in the sample from the “C”-zone monitoring well (well MW508C; Figure 2.11).
18 The highest concentration of TCE detected in any of the three wells from the cluster (20
19 µg/L, in the sample from well MW508B) is the value presented on Figure 2.13.
20 Therefore, the lateral extent of TCE in groundwater shown on Figure 2.13 (shaded areas)
21 is an interpretation of the areas within which detectable concentrations of TCE may be
22 present in groundwater, and is based on the thematic representation of the entire area
23 within which TCE has been detected in at least one depth interval of the water-bearing
24 unit.

25 In a heterogeneous groundwater system, as is present at DDJC-Sharpe (Figure 2.14),
26 preferential migration of contaminants is likely to occur within the more coarse-grained
27 (sandy) strata in the subsurface (Section 2.2.3.3), as a consequence of the greater
28 hydraulic conductivity of these strata (as compared with intervening finer-grained
29 materials). If a series of more-permeable strata are interconnected to some degree,
30 migration to extended distances and significant depths can occur along these pathways.

1

2 **Figure 2.13 Extent of TCE in Groundwater Third Quarter 1999**

3

1 **Figure 2.14 Conceptual Schematic Diagram of Dissolved Contaminant Migration in**
2 **a Heterogeneous Groundwater System**

3

Migration also will occur, albeit at slower rates, through zones consisting of silty sands, and through thinner sandy interbeds within finer-grained materials (silts and clays) (Figure 2.14). As a consequence of the slow rate of contaminant migration through finer-grained (less permeable) materials, and along thin sand stringers, dissolved contaminants trapped in these units can function as secondary sources of contaminants in the subsurface, contributing contaminant mass to groundwater through extended periods of time.

Mechanisms by which contaminants can migrate to increasingly greater depths in a heterogeneous groundwater system, under the influence of a downward hydraulic gradient, are illustrated conceptually in Figure 2.14. The actual hydrologic system at DDJC-Sharpe is even more complex than shown schematically, in that the magnitudes and directions of horizontal or vertical hydraulic gradients can change through time. The areal extent and maximum concentrations of TCE in groundwater in the four zones are summarized in Table 2.4, for the third quarter 1999 sampling event, based on information presentation by Radian (1999g).

TABLE 2.4
EXTENT AND CONCENTRATIONS OF TCE IN GROUNDWATER^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Hydrogeologic Unit	Plume Location	Highest Concentration of TCE (µg/L) ^{b/}	Maximum Depth Affected (ft bgs) ^{c/}	Areal Extent (ft ²) ^{d/}
"A" Zone	South Balloon Area, Central Area, North Balloon Area	210	30	86,700
"B" Zone	South Balloon Area, Central Area, North Balloon Area	430	90	123,650
"C" Zone	South Balloon Area, Central Area, North Balloon Area	800	140	82,200
"D" Zone	North Balloon Area	6.5	160	700

^{a/} Concentrations of TCE reported for the monitoring event of 3rd Quarter 1999 (Radian, 1999g).

^{b/} µg/L = micrograms per liter.

^{c/} ft bgs = feet below ground surface.

^{d/} ft² = square feet.

1 Temporal changes in hydraulic gradients (and hence, migration directions), contribute
2 to the variability in contaminant concentrations throughout the groundwater system.

3 Significant variation in TCE concentrations occurs with location and depth in the
4 actual groundwater system at DDJC-Sharpe, in that TCE concentrations in one depth
5 interval (e.g., monitoring zone “A”) at a particular location may differ from
6 concentrations in another depth interval (e.g., monitoring zone “C”) at the same location,
7 by a factor of 10 or more. This is a result of the heterogeneities in the water-bearing unit,
8 as presented conceptually in Figure 2.14, and also is a consequence of spatial changes in
9 local hydraulic gradients, which vary with location and depth (c.f., Section 2.2.3.4;
10 Figure 2.7). The influence of local hydraulic gradients on dissolved contaminant
11 migration is shown schematically on Figure 2.15, which presents a cross-section along
12 the axis of the plume in the South Balloon area (cross-section location shown on Figure
13 2.13). The location of the cross-section is identical to that of the hydraulic cross-section
14 presented in Figure 2.7, and was selected to best represent local variability in hydraulic
15 gradients, while remaining as close to the axis of the TCE plume as possible. The
16 schematic depiction of the distribution of TCE in groundwater at DDJC-Sharpe has been
17 represented as being more homogeneous and continuous than likely occurs in the actual
18 groundwater system, because the discrete migration pathways that control the movement
19 of dissolved TCE cannot realistically be identified and presented. Nevertheless, despite
20 the simplifications inherent in the schematic representation (Figure 2.15), the possibility
21 that downward migration of TCE in groundwater from the “A” zone into the “B” and “C”
22 zones may have been induced by the downward gradients resulting from pumping of C”-
23 zone extraction wells and local agricultural wells, is clearly apparent.

24 The extent of TCE in groundwater in the third quarter of 1999 (Figure 2.13) was
25 compared with the extent of TCE in groundwater in 1990 (Figure 2.16), in order to
26 examine the effects of attenuation processes and active groundwater ETI, operating over
27 a 10-year period, on the migration and persistence of TCE in the subsurface. Figures
28 2.13 and 2.16 were similarly constructed, in that a depiction of the lateral extent of TCE
29 in groundwater throughout the entire water-bearing unit was generated by considering all
30 of the TCE concentration results obtained during a relatively short time period (1990)

1

2 **Figure 2.15 Conceptual Diagram Showing Vertical Distribution of TCE in**
3 **Groundwater Along Section A-A', South Balloon Area**

4

1 **Figure 2.16 Extent of TCE in Groundwater 1990**

2

1 together, rather than grouping the results by groundwater monitoring zone. The
2 concentrations of TCE, presented thematically at each monitoring point indicated on
3 Figures 2.13 and 2.16, are the highest concentrations detected in groundwater from an
4 individual well within a well cluster at that location in third quarter 1999 and 1990,
5 respectively, regardless of the depth interval from which the sample was collected.

6 The TCE plume in the South Balloon and Central Area appears to have decreased in
7 areal extent during the period 1990 through the third quarter of 1999 (compare Figures
8 2.13 and 2.16). In particular, the off-facility lobes of the plume have receded; and the
9 concentrations of TCE within the plume generally were lower in the third quarter of 1999
10 than in 1990. The apparent decreases in the extent and concentrations of TCE in
11 groundwater probably have resulted from a combination of factors including:

- 12 1. a reduction in TCE mass and/or concentrations resulting from natural
13 attenuation processes operating between 1990 and 1999;
- 14 2. hydraulic containment of TCE in some of the more distal areas of the plume;
15 and
- 16 3. changes in hydraulic gradients (and resultant groundwater flow directions) due
17 to active groundwater extraction and injection.

18 The apparent reduction in the extent and concentrations of TCE in groundwater
19 occurred during a period in which subsurface conditions at DDJC-Sharpe were
20 progressively better characterized. By contrast, the apparent increase in extent of TCE in
21 groundwater of the North Balloon area between 1990 and the third quarter of 1999
22 appears to be an artifact of sampling, in that groundwater samples were collected from
23 nearly twice as many wells in 1999 as in 1990, thereby providing more information with
24 which to better define the extent of TCE.

2.3.2.3 Other COCs in Groundwater

Arsenic

Arsenic is naturally present as a minor or trace constituent in many earth materials, including soils of the Central Valley of California (Shacklette and Boerngen, 1984), and can become dissolved in groundwater or surface water in contact with those materials (Hem, 1989). The behavior and mobility of arsenic in groundwater is strongly dependent upon local geochemical conditions in the groundwater system (Appendix B, Section B2.8.1). In particular, changes in the local oxidation/reduction potential can greatly affect the mobility of arsenic in the environment.

Since 1982, more than 3,700 groundwater samples, collected from 240 monitoring wells at DDJC-Sharpe, have been analyzed for arsenic. Historically, arsenic has been detected in groundwater samples from approximately 50 monitoring wells at concentrations that exceed 50 µg/L (the federal MCL for arsenic). Most recently (third quarter 1999 groundwater monitoring event), arsenic concentrations in groundwater samples from nine monitoring wells exceeded the MCL for arsenic (Figure 2.17). The results of the RI/FS (ESE, 1990; *ibid.*, 1991a), and of recent sampling events (Radian, 1999g), indicate that no apparent spatial correlation exists between areas in which VOC contaminants are present in groundwater and areas in which arsenic is present in groundwater.

To assist in assessing the occurrence of arsenic in the subsurface at DDJC-Sharpe, and interpreting potential changes in its migration characteristics associated with redox conditions and other processes, Parsons collected 27 groundwater samples during the sampling event of July and August 2000, for analysis of two species of arsenic [arsenic (III) and arsenic (V)]. In all but one groundwater sample, arsenic (V) concentrations were greater than arsenic (III) concentrations by approximately three orders of magnitude (Table 2.5). The concentration of arsenic (III) was greater than the concentration of arsenic (V) in only a single groundwater sample – the sample from well MW514B, which also had a low value of oxidation-reduction potential (ORP) (Section 2.3.3.2). The occurrence of arsenic (V) (probably as arsenate; Appendix B) as the prevailing arsenic

1

2 **Figure 2.17 Distribution of Arsenic in Groundwater 1998 – 1999**

3

TABLE 2.5
CONCENTRATIONS OF ARSENIC IN GROUNDWATER SAMPLES
SAMPLING EVENT OF JULY-AUGUST 2000
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Sampling Location	Sampling Date	As(III) ^{a/} (mg/L) ^{b/}	As (Total) (mg/L)	As(V) ^{a/} (mg/L)
Sample Locations in North Balloon Area				
MW413B	07/27/00	0.032	15.100	15.068
MW421A	07/27/00	0.886	128.000	127.114
MW438A	07/26/00	0.053	15.500	15.447
MW456B	07/26/00	0.020 B ^{c/}	8.720	8.700 B
MW477A	07/28/00	0.264	80.500	80.236
MW514B	08/02/00	15.100	16.200	1.100
MW517A	08/02/00	0.565	119.000	118.435
MW517A (dup) ^{d/}	08/02/00	0.561	121.000	120.439
MW521B	08/03/00	0.023	12.800	12.777
Sample Locations in Central Area				
MW417A	08/04/00	0.134	41.800	41.666
MW417B	07/26/00	0.011 B	7.010	6.999 B
MW423A	07/25/00	0.087	22.300	22.213
MW437B	07/28/00	0.054	9.240	9.186
MW443A	07/27/00	0.245	53.200	52.955
MW507A	08/02/00	0.171	54.300	54.129
MW507C	08/02/00	0.072	19.300	19.228
Sample Locations in South Balloon Area				
DW001	07/25/00	0.038	11.200	11.162
MW403A	07/27/00	1.800	400.000	398.200
MW406A	07/27/00	0.052	19.900	19.848
MW407A	07/26/00	2.370	368.000	365.630
MW418B	07/28/00	0.063	16.100	16.037
MW418C	07/28/00	0.085	20.000	19.915
MW422A	08/03/00	0.093	24.500	24.407
MW440A	07/31/00	0.746	290.000	289.254
MW440B	08/01/00	0.158	50.400	50.242
MW441C	07/27/00	0.028	14.300	14.272
MW445C	07/26/00	0.012 B	8.260	8.248 B
MW476A	07/28/00	0.020 B	13.600	13.580 B
MW476A (dup)	07/28/00	0.047	12.100	12.053

^{a/} Groundwater samples were analyzed for As(III) and total As. Values for As(V) were calculated by subtraction.

^{b/} µg/L = micrograms per liter.

^{c/} Data value is above method detection limit but below reporting limit.
The reported value has been estimated.

^{d/} "(dup)" indicates that the sample is a field duplicate of the primary sample, collected on the same day.

1 species in groundwater has important environmental implications for DDJC-Sharpe, in
2 that arsenic (V) is generally less mobile in the environment than arsenic (III), and is
3 readily sorbed to many types of earth materials.

4 The distribution of arsenic across the facility is variable (Figure 2.17), with higher
5 concentrations of arsenic generally being detected in groundwater samples from the “A”
6 zone. Fifteen of the 27 wells sampled by Parsons in July-August 2000 are completed in
7 the “A” zone (Table 2.5), and the other 12 wells that were sampled are completed in the
8 “B” or “C” zones. The concentrations of arsenic detected in approximately one-half of
9 the groundwater samples collected from the “A” zone exceeded the MCL for arsenic of
10 50 µg/L; but only one groundwater sample from deeper zones (the sample from well
11 MW440B) contained arsenic at a concentration greater than 50 µg/L (50.4 µg/L; Table
12 2.5).

13 In 1999, the concentrations of arsenic, nitrate, and selenium in groundwater,
14 representative of “background” conditions (i.e., locations unaffected by historic
15 operations at DDJC-Sharpe) were reviewed (Radian, 1999g), for the purpose of
16 evaluating the range of concentrations of these constituents that might occur naturally in
17 groundwater, in the absence of impacts from the facility. The results of analyses of
18 groundwater samples, collected from 11 wells in locations considered to be outside the
19 area of influence of facility activities, were compiled and analyzed using statistical
20 methods. The concentrations of arsenic, nitrate, and selenium in groundwater
21 representative of “background” conditions, were calculated as the 95/95 upper tolerance
22 limits (UTLs) for these constituents in groundwater samples from each monitoring zone
23 (Table 2.6). The 95/95 upper tolerance limit is the concentration that represents the 95th
24 percentile of the statistical distribution of arsenic concentrations, at the 95-percent
25 confidence level. Comparison of an arsenic concentration in a groundwater sample with
26 the 95/95 UTL concentration of arsenic can be used to evaluate whether arsenic in
27 groundwater at the sampling location is naturally-occurring, or is an anthropogenic
28 contaminant. Concentrations of arsenic that are equal to or below the 95/95 UTL
29 concentration of arsenic (Table 2.6) are presumed to be representative of “background”

TABLE 2.6
BACKGROUND CONCENTRATIONS OF ARSENIC, NITRATE, AND
SELENIUM IN GROUNDWATER^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Analyte	Number of Samples ^{b/}	Concentrations				
		Maximum ^{c/}	Mean ^{d/}	Median ^{e/}	Minimum ^{f/}	95/95 UTL ^{g/}
Groundwater in Shallow (“A”) Zone						
Arsenic	55	279 µg/L ^{h/}	125 µg/L	152 µg/L	7.9 µg/L	279 µg/L
Nitrate	35	24.2 mg/L ^{i/}	8.45 mg/L	8.1 mg/L	ND ^{j/}	20.9 mg/L
Selenium	39	24.4 µg/L	4.26 µg/L	ND	ND	24.4 µg/L
Groundwater in Mid- (“B” and “C”) Zones						
Arsenic	22	57 µg/L	25.8 µg/L	16.5 µg/L	8.1 µg/L	57 µg/L
Nitrate	21	3.9 mg/L	1.38 mg/L	1.4 mg/L	ND	3.9 mg/L
Selenium	21	7.6 µg/L	1.8 µg/L	ND	ND	7.6 µg/L
Groundwater in Deep (“D”) Zone						
Arsenic	21	22.6 µg/L ^{h/}	11.9 µg/L	10.4 µg/L	ND	25.5 µg/L
Nitrate	21	3.8 mg/L ^{i/}	0.529mg/L	ND	ND	3.8 mg/L
Selenium	21	ND	NC ^{k/}	NC	ND	NC

^{a/} Results developed and reported by Radian (1999g).

^{b/} Total number of samples collected from each monitoring zone at locations judged to be representative of naturally-occurring (or “background”) conditions, used to develop summary statistics.

^{c/} “Maximum” = maximum concentration detected in sample set from a particular monitoring zone.

^{d/} “Mean” = arithmetic average of concentrations detected in sample set from a particular monitoring zone.

^{e/} “Median” = median of concentrations detected in sample set from a particular monitoring zone.

^{f/} “Minimum” = minimum concentration detected in sample set from a particular monitoring zone.

^{g/} 95/95 UTL = upper tolerance limit concentration representing the 95th percentile of the statistical distribution of constituent concentrations, at the 95-percent confidence level.

^{h/} µg/L = micrograms per liter.

^{i/} mg/L = milligrams per liter.

^{j/} ND = concentration of constituent was below the detection limit.

^{k/} NC = statistic not calculated, because all concentrations were below the reporting limit.

conditions, while concentrations of arsenic that exceed the 95/95 UTL are presumed to be a consequence of anthropogenic contamination (Radian, 1999g).

Comparison of the concentrations of total arsenic detected in groundwater samples, collected during July and August 2000 (Table 2.5), with the 95/95 UTL concentrations for arsenic (Table 2.6), indicates that the concentrations of arsenic in all groundwater samples from wells completed in the “B” and “C” zones are representative of naturally-occurring (“background”) concentrations of arsenic. The concentrations of arsenic in all

groundwater samples from wells completed in the “A” zone in the North Balloon and Central Area also are representative of “background” conditions. Only the samples from wells MW403A, MW407A, and MW440A, completed in the “A” zone in the South Balloon area, contained arsenic at concentrations that exceeded the 95/95 UTL value for arsenic. Apparently, most arsenic in groundwater at DDJC-Sharpe is naturally occurring. The source of arsenic that may represent anthropogenic contamination in groundwater at the South Balloon currently is not known, although it is possible that arsenic in this area is associated with past uses of insecticides, herbicides, or fertilizers in the area.

The extent of arsenic in groundwater appears to have remained relatively stable through time (note general lack of temporal trends on Figure 2.17), perhaps as a result of the current pH and ORP conditions in groundwater at DDJC-Sharpe. In the absence of significant environmental changes (e.g., changes in redox conditions, increased infiltration or movement of water, increases in loading of ionic or elemental constituents), equilibrium conditions will be maintained, and the extent and concentrations of arsenic in groundwater should remain stable. However, if conditions in groundwater locally become more reducing, the mobility of arsenic could increase.

Selenium and Nitrate

Selenium and nitrate also are naturally-occurring trace constituents in soils of the Central Valley of California (Shacklette and Boerngen, 1984), and can become dissolved in groundwater or surface water in contact with those materials (Hem, 1989). Nitrogen also is a common constituent of fertilizers and sewage sludge. The behavior and mobility of selenium and nitrate in groundwater are strongly dependent upon local geochemical conditions in the groundwater system (Appendix B, Section B2.8.2). In particular, changes in local pH can greatly affect the mobility of selenium in the environment.

A total of 164 groundwater samples, collected in January 1988, were analyzed for selenium (ESE, 1990). Selenium was detected in thirty-nine of the samples, at concentrations above the reporting limit (5.2 µg/L), while 11 of the 39 samples contained selenium at concentrations that exceeded the California State Action Level (CSAL) of 10 µg/L. Ten of the 11 groundwater samples exceeding the CSAL for selenium were

1 collected from the “A” monitoring zone; and one sample having a selenium exceedance
2 was collected from monitoring well MW421B, completed in the “B” zone. Since 1995,
3 selenium has been detected in groundwater samples from 10 wells (wells EWC2,
4 EWCA1, EWNA6, EWNA7, EWNA10, MW413B, MW420B, MW38A, MW477A, and
5 MW521A) at concentrations that exceeded the CSAL for selenium; but selenium has
6 been detected at concentrations that exceeded naturally-occurring (“background”)
7 concentrations calculated for particular monitoring zones (Table 2.6) in only five
8 groundwater samples (samples collected from wells MW413B and MW420B in February
9 2000; and samples collected from wells EWNA6, MW438A, and MW420B in July,
10 2000) (Radian, 2000a).

11 Since 1995, nitrate has been detected in groundwater samples from 9 wells (sample
12 collected from well MW440A in April 1999; samples collected from wells DW001,
13 DW003, MW402A, MW418AR, and MW445A in September 1999; samples collected
14 from wells MW441C, MW442B, MW442C, and MW445A in October 1999; and samples
15 collected from wells DW003 and MW445A in February 2000) (Radian, 2000a), at
16 concentrations that exceeded naturally-occurring (“background”) concentrations
17 calculated for particular monitoring zones (Table 2.6). Elevated concentrations of nitrate
18 in groundwater at these locations is likely a result of agricultural application of nitrogen-
19 based fertilizers, on the facility or in surrounding areas.

20 **Pesticides/Herbicides/PCBs**

21 A total of 19 wells were sampled for pesticides/PCBs and the herbicide bromacil
22 during the groundwater monitoring event completed in the third quarter of 1999 (Radian,
23 1999g). Bromacil was detected in 16 of the 18 samples that were analyzed for bromacil.
24 The distribution of bromacil across the facility is variable (Figure 2.18), with higher
25 concentrations of bromacil generally detected in groundwater samples from the “A” zone,
26 and the highest concentrations of bromacil detected in samples from wells located near
27 the facility boundaries. Bromacil is a commonly-used herbicide (Appendix B, Section
28 B2.7), and its occurrence in groundwater in the vicinity is suspected to be a consequence
29 of its normal and intended use in nearby agricultural applications (Radian, 1999g). The

1

2 **Figure 2.18 Distribution of Bromacil in Groundwater 1998 – 1999**

3

1 extent of bromacil in groundwater appears to have remained relatively stable through
2 time (note general lack of temporal trends on Figure 2.18), perhaps as a result of its
3 continued application on surrounding agricultural lands.

4 Organochlorine pesticides and PCBs were not detected in groundwater samples
5 collected from monitoring or extraction wells during the 1999 sampling event, and PCBs
6 historically have not been detected in any groundwater sample collected at DDJC-Sharpe
7 (Radian, 1999g).

8 **2.3.3 Evaluation of Natural Attenuation Potential of Chlorinated Solvents at DDJC-** 9 **Sharpe**

10 The potential for the natural attenuation mechanisms to remove chlorinated aliphatic
11 hydrocarbon compounds (CAH), such as TCE and DCE, from groundwater at DDJC-
12 Sharpe was examined in conjunction with this RPO evaluation. The available
13 information may be used to assess qualitatively the contribution of natural attenuation in
14 removing VOCs from the subsurface, and to project the feasibility of using MNA as a
15 remediation approach that would complement active groundwater extraction and
16 treatment. In addition, this information will be useful in evaluating the long-term
17 monitoring program at DDJC-Sharpe.

18 Natural attenuation mechanisms include biodegradation, dispersion, dilution from
19 recharge, sorption, and volatilization (USEPA, 1998). Of these processes, biodegradation
20 is the only mechanism working to transform contaminants into innocuous byproducts,
21 thereby removing contaminant mass from the subsurface. Intrinsic bioremediation occurs
22 when indigenous microorganisms work to bring about a reduction in the total mass of
23 contaminants in the subsurface without the addition of nutrients or other amendment.
24 The principal biodegradation processes that affect CAH are reviewed in Appendix B.

25 The evaluation focused on the biodegradation of TCE and its daughter products
26 (primarily *cis*-1,2-DCE). The following information was used to conduct the natural
27 attenuation evaluation:

- 1 • The existing database was reviewed to identify daughter products that occur in
2 association with TCE in the plumes of dissolved CAH.
- 3 • Geochemical data collected by Parsons from 42 wells during the sampling event of
4 July and August 2000 (Figure 2.19 and Table 2.7) were interpreted to assess
5 geochemical and redox conditions in the groundwater system at DDJC-Sharpe.
- 6 • Geochemical data collected by Radian from seven North Balloon wells (MW421A,
7 MW438A, MW439A, MW456A, MW477A, MW484A, and MW517A) also were
8 reviewed to assess geochemical and redox conditions, and the occurrence of natural
9 attenuation.

10 The following subsections present the interpretation of these site-specific data and an
11 assessment of the potential for natural attenuation processes to limit the migration of
12 dissolved CAH, and to reduce the concentrations, mass, and/or toxicity of CAH in
13 groundwater through time.

14 **2.3.3.1 TCE Daughter Products and Organic Carbon Sources**

15 One of the most straightforward methods of evaluating the occurrence of
16 biodegradation processes is to examine the distribution of TCE (the parent species) and
17 its spatial and temporal association with the products of degradation reactions (“daughter
18 products”) (Appendix B). It also may be useful to examine the spatial distribution of
19 other anthropogenic contaminants (e.g., fuel hydrocarbons) or native organic carbon that
20 may function as sources of electron donors.

21 Reductive dehalogenation is the most commonly occurring biodegradation reaction
22 (Appendix B). Dehalogenation of TCE sequentially generates a succession of daughter
23 products, DCE isomers, vinyl chloride, and ethene, ethane, or methane. A typical pattern
24 of contaminant and daughter-product distribution would consist of TCE at its highest
25 concentrations near the chemical source area(s), with elevated concentrations of DCE
26 isomers (consisting primarily of *cis*-1,2-DCE) within and just downgradient from (or
27 surrounding) the source area (Vogel, 1994; USEPA, 1998). At downgradient locations,
28 the concentrations of TCE and DCE would gradually decrease with increasing distance

1

2 **Figure 2.19 Locations of Wells Sampled During July – August 2000 for Collection**
3 **of Geochemical Data**

4

TABLE 2.7
GROUNDWATER GEOCHEMICAL DATA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Well ID	Date Sampled	pH	Redox Potential (mV) ^{a/}	Temperature (°C) ^{b/}	Dissolved Oxygen (mg/L) ^{c/}	Conductivity (mS/cm) ^{d/}	Turbidity (NTU) ^{e/}	Alkalinity (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Total Organic Carbon (mg/L)
Sample Locations in North Balloon Area													
MW413B	7/27/2000	7.39	264.0	20.03	1.19	1,165	0.37	430	3	11	0.01	0.5	25
MW421A	7/27/2000	8.09	234.6	20.67	2.97	977	1.32	300	25	6.6	0.02	0.1	9
MW421B	8/1/2000	7.45	267.4	22.20	0.63	795	0.34	165	48	0.4	0.00	0.6	2
MW438A	7/26/2000	7.27	251.0	20.74	1.88	1,140	0.4	350	9	14	0.00	0.1	7
MW456B	7/26/2000	7.23	224.0	21.10	0.30	1,272	0.47	400	11	0.6	0.01	0.5	3
MW464C	8/1/2000	8.23	226.3	21.82	0.38	394	2.97	120	23	3	0.01	0	2
MW477A	7/28/2000	7.48	266.3	21.05	1.11	2,849	0.78	1500	0.06	4.6	0.00	42	28
MW484A	8/1/2000	7.32	281.4	23.15	1.10	1,405	0.68	330	50	10	0.00	1.2	5
MW514B	8/2/2000	7.53	-41.1	19.99	0.81	910	1.03	160	45	< 1	0.00	1.5	27
MW517A	8/2/2000	7.70	268.7	18.64	0.63	712	0.38	145	1	0.9	0.00	0.8	4
MW521B	8/3/2000	7.55	271.9	20.64	0.80	923	0.33	140	47	8	0.00	0.5	2
MW522C	8/4/2000	7.76	266.5	20.22	1.12	751	0.39	70	30	3.8	0.00	0.5	< 1
Sample Locations in Central Area													
MW419B	8/1/2000	7.53	269.8	19.62	4.00	545	0.4	100	51	2.3	0.00	1.2	3
MW423A	7/25/2000	7.63	138.5	23.04	5.15	824	0.33	300	31	15	0.00	0.1	17
MW437B	7/28/2000	7.34	277.9	20.67	0.38	793	0.79	200	74	5.9	0.00	0.07	2
MW443A	7/27/2000	7.78	262.2	20.90	6.20	491	1.24	185	22	8.8	0.00	0.5	2
MW446A	8/3/2000	7.70	263.9	25.42	1.04	711	67.1	200	50	2.6	0.18	0.9	2
MW452A	8/4/2000	7.79	233.2	22.99	0.42	753	13.2	NM	59	1.8	0.06	0.9	15
MW460C	7/31/2000	7.82	276.7	21.39	0.50	349	0.76	120	29	1.1	0.00	0	2
MW501B	8/3/2000	7.62	276.6	19.44	0.49	356	0.88	90	26	1.9	0.01	0	1
MW507A	8/2/2000	7.22	295.5	22.65	3.82	2,970	0.61	500	96	58	0.00	0.8	39
MW507C	8/2/2000	8.25	218.3	20.28	1.98	344	0.5	90	14	1	0.00	0	2
MW510C	8/4/2000	7.18	285.2	19.96	0.18	1,093	0.21	300	48	1.8	0.10	0.8	5
MW524A	8/3/2000	7.26	307.1	20.71	7.53	1,062	0.45	140	65	23	0.01	0.5	1
Sample Locations in South Balloon Area													
DW001	7/25/2000	7.24	147.0	23.96	0.49	1,259	41	410	65	21	0.00	0.3	12
MW403A	7/27/2000	7.94	252.6	20.47	6.84	1,327	1.08	400	14	9.9	0.00	0	26
MW406A	7/27/2000	7.54	259.7	21.15	7.22	814	1.2	290	13	15	0.00	0.1	2
MW407A	7/26/2000	7.79	248.0	19.68	7.03	2,204	0.72	950	24	32	0.01	0.5	13
MW417A	8/4/2000	7.42	275.4	23.82	2.68	2,178	8.6	NM ^{f/}	68	21	0.01	0.7	9
MW417B	7/26/2000	7.11	210.8	20.85	0.52	1,624	0.31	850	14	6.8	0.03	0.8	12
MW418B	7/28/2000	7.62	146.7	22.00	0.64	627	0.85	225	41	4.7	0.02	0.9	2
MW418C	7/28/2000	7.89	223.7	21.33	0.72	331	0.76	145	15	2.9	0.00	0.04	< 1 ^{g/}
MW422A	8/3/2000	7.64	251.8	24.75	0.79	901	39.1	130	63	15	0.05	0	19
MW427C	8/1/2000	7.82	284.3	21.25	1.36	435	0.4	120	22	6.2	0.00	0.2	2
MW429A	8/2/2000	7.57	268.0	28.42	1.10	435	5.57	112	19	0.1	0.00	0.2	1
MW440A	7/31/2000	7.73	269.9	23.62	0.88	1,591	0.68	250	60	14	0.00	0	9
MW440B	7/31/2000	7.87	261.0	22.02	0.55	1,327	0.42	140	52	6.4	0.01	0.2	4
MW441B	8/1/2000	7.62	294.5	21.71	1.00	498	0.6	160	24	4.3	0.00	0	5
MW441C	7/27/2000	7.64	214.4	20.77	0.43	537	0.58	190	28	0.6	0.03	0	1
MW445C	7/26/2000	7.17	241.9	21.09	0.88	1,461	0.76	340	17	14	0.00	1.5	7
MW476A	7/28/2000	7.00	297.3	20.46	1.54	1,580	0.59	350	26	21	0.00	0.2	12
MW501A	8/3/2000	7.58	256.6	22.19	0.67	362	0.66	140	25	2.6	0.00	0	1

^{a/} mV = millivolts.

^{b/} °C = degress Centigrade.

^{c/} mg/L = milligram per liter.

^{d/} mS/cm = microsiemens per centimeter.

^{e/} NTU = nephelometric turbidity units.

^{f/} NM = not measured.

S:\ES\Remed\RPO\DDJC-Sharpe\Tables\Master Tables.xls Table 2.7<sup>g/

1 from the source; and the ratio of DCE concentrations to TCE concentrations might
2 increase. Vinyl chloride (VC) could be present throughout the CAH plume, with the
3 highest VC concentrations likely to be found in areas that are neither strongly reducing
4 nor oxidizing.

5 One or more DCE isomers (including 1,1-DCE, *cis*-1,2-DCE, and *trans*-1,2-DCE)
6 historically have been detected in over 1,000 groundwater samples - about one-third of
7 the samples in which TCE also has been detected. DCE isomers have been detected in
8 groundwater samples from wells in the North Balloon, Central, and South Balloon areas
9 at DDJC-Sharpe, and in groundwater samples from the "A", "B", "C", and "D"
10 monitoring zones (Table 2.8), primarily in samples from wells located along plume axes,
11 where TCE concentrations are highest (Figure 2.20). The most commonly detected DCE
12 isomer is *cis*-1,2-DCE, with *trans*-1,2-DCE and 1,1-DCE each detected at much lower
13 frequencies. In general, all groundwater samples that contained *trans*-1,2-DCE or 1,1-
14 DCE also contained *cis*-1,2-DCE at higher concentrations (up to 85 µg/L). Without
15 exception, TCE also was detected in all samples in which DCE was detected. The co-
16 occurrence of TCE and DCE isomers in the same samples indicates that DCE in
17 groundwater at DDJC-Sharpe is probably a degradation product of TCE. At several
18 locations (c.f., wells MW507A, MW507B, and MW507C in the Central Area), DCE
19 isomers have been detected in samples from several wells in a cluster, completed at
20 different depth intervals in the groundwater system, indicating that conditions locally are
21 favorable for the degradation of TCE.

22 VC has been detected only sporadically in groundwater at DDJC-Sharpe, and in fact
23 has been detected historically in samples from only a single monitoring well (well
24 MW477A, located in the North Balloon). The infrequent detection of VC may indicate
25 that dehalogenation of *cis*-1,2-DCE to VC is proceeding very slowly, or may indicate that
26 VC is degraded (to ethane, ethane, or carbon dioxide and water) as rapidly as it is
27 generated during dehalogenation reactions (Appendix B).

1

2 **Figure 2.20 Locations of Wells with Historical Detections of TCE Daughter**
3 **Products and Petroleum Hydrocarbons**

4

TABLE 2.8
OCCURRENCE OF *cis*-1,2-DCE IN GROUNDWATER
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Wells at Which <i>cis</i> -1,2-DCE Has Been Detected in Groundwater Samples		
North Balloon Area	Central Area	South Balloon Area
MW412D	MW437C	DW001
MW421A	MW443A	DW002
MW421B	MW443B	DW003
MW421C	MW446B	DW004
MW438A	MW454B	MW402A
MW438B	MW455B	MW402B
MW439A	MW457A	MW407A
MW439B	MW457B	MW407B
MW456B	MW504C	MW418AR
MW477A	MW507A	MW418B
	MW507B	MW418C
	MW507C	MW424A
	MW523AB	MW425A
		MW427A
		MW433B
		MW434B
		MW441A
		MW445C
		MW473A
		MW475A
		MW476A

Organic Carbon Sources

A number of soil samples, collected at various depths in the subsurface, historically have been analyzed for TOC (Appendix B, Table B.3). Organic carbon has been detected in soil samples, at concentrations ranging from about 0.002 percent (by weight) to 0.006 percent. The concentrations of TOC in groundwater samples collected by Parsons during the period July through August, 2000 ranged from less than one milligram per liter

(mg/L) to 30 mg/L (Table 2.5). Organic carbon was detected in all but two samples. A review of the historical database (Radian, 2000a) indicates that petroleum hydrocarbons have been detected in groundwater samples from nine wells at various locations on the facility (Figure 2.20). The occurrence of native and anthropogenic carbon sources provide conditions in groundwater that are favorable to biodegradation of CAH.

2.3.3.2 Redox Couples in Biodegradation

Microorganisms can facilitate the biodegradation (oxidation) of carbon compounds only by using redox couples that have a higher ORP than the contaminants. Figure 2.21 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981). The reduction of highly oxidized species (e.g., TCE) results in an overall decrease in the oxidizing potential of the groundwater. As shown on Figure 2.21, the reduction of oxygen and nitrate will decrease the oxidizing potential to levels at which ferric iron reduction can occur. As each chemical species that can be used to oxidize the contaminants is depleted, the microorganisms are forced to use other available electron acceptors having lower oxidizing capacity. When sufficiently low (negative) ORP levels have developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

ORP values measured in groundwater at DDJC-Sharpe in July and August 2000 ranged from -41 millivolts (mV) in well MW514B to +307 mV at well MW524A (Table 2.7 and Figure 2.21). The ORP value of -41 mV is anomalously low, as the ORP measured in groundwater at the remaining 41 wells was in the range of 147 to 307 mV. ORP levels this high would probably not produce sufficiently reducing conditions to support significant iron or sulfate reduction and methanogenesis (Figure 2.21). On the other hand, the relative uniformity of ORP measured in samples having ORP values greater than 147 mV (Table 2.7) indicates that some oxygen contamination of groundwater could have occurred during the sampling process.

1

2 **Figure 2.21 Sequence of Microbially Mediated Redox Processes**

3

2.3.3.3 Electron Acceptors

Biodegradation of natural and anthropogenic organic compounds brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., dissolved oxygen, nitrate, and sulfate) are depleted, and the concentrations of byproducts of electron-acceptor reduction (e.g., ferrous iron, methane, and sulfide) are increased (Appendix B). By measuring these changes, it is possible to evaluate the degree to which natural attenuation mechanisms are occurring at a site.

Dissolved Oxygen

The concentrations of dissolved oxygen measured in groundwater during the sampling event of July and August 2000 at DDJC-Sharpe (Section 2.1.3) ranged from 0.18 to 7.53 mg/L, with the lowest DO concentration detected at well MW510C, and the highest at well MW524A (Table 2.7). Both wells are located off-facility west of the Central Area (Figure 2.19) where contaminant levels are currently low to non-detectable. The DO values varied widely throughout this range in areas within, and outside of the dissolved CAH plumes. However, DO levels in most groundwater samples were near or less than 1 mg/L. It is possible that some of the elevated DO levels (greater than 1 or 2 mg/L) occur as a result of movement of oxygenated groundwater into the plume area under the influence of groundwater extraction, or from oxygenated water entering the subsurface from percolation ponds and injection wells located in the Central Area. The relatively depressed DO levels in most of the groundwater samples (1 mg/L or less) may be a result of oxygen consumption during aerobic degradation of native total organic carbon (TOC) or anthropogenic carbon (from fuel spills, etc.) in groundwater.

Dehalogenation reactions generally proceed most effectively under anaerobic conditions (concentrations of DO are less than about 1 mg/L) (USEPA, 1998). Therefore, the levels of DO through much of the groundwater system appear to provide conditions suitable for degradation of CAH.

1 **Nitrate**

2 After DO has been depleted in the subsurface, nitrate may be used as an electron
3 acceptor for anaerobic biodegradation of organic carbon via denitrification (Appendix B).
4 Nitrate was detected in all but one of the samples that were analyzed for nitrate in July
5 and August 2000 (Table 2.7). Nitrate concentrations ranged from less than 1 mg/L (in
6 the sample from well MW514B) to 58 mg/L (in the sample from well MW507A). Both
7 wells are located off-facility west of the Central Area (Figure 2.19). The concentrations
8 of nitrate in most groundwater samples were less than 10 mg/L. No spatial trends in
9 nitrate concentrations in groundwater are apparent. The cause of elevated nitrate
10 concentrations (greater than 10 mg/L) in groundwater at some locations is not known, but
11 may be a consequence of past sewage disposal or agricultural practices.

12 **Sulfate**

13 Sulfate is reduced to sulfide during oxidation of natural or anthropogenic carbon
14 (Appendix B). Sulfate was detected in all groundwater samples, at concentrations
15 ranging from 0.06 mg/L (in the sample from well MW477A, located in the North
16 Balloon), to 96 mg/L (in the sample from well MW507A, located in the Central Area)
17 (Table 2.7 and Figure 2.19). Sulfate concentrations varied widely throughout this range;
18 no spatial trends in sulfate concentrations in groundwater are apparent.

19 Sulfide was not detected in any of the groundwater samples, recently collected from
20 seven wells (including well MW477A), by Radian, in conjunction with their natural
21 attenuation evaluation (Radian 1999b). Based on these data, it does not appear that
22 conditions in groundwater at DDJC-Sharpe are sufficiently reducing to support
23 significant sulfate reduction.

24 **2.3.3.4 Metabolic Byproducts**

25 Geochemical data collected during July and August 2000 (Table 2.7) indicate that low
26 concentrations of ferrous iron (Fe^{2+}) and soluble manganese (Mn^{2+}) occur in groundwater
27 in some parts of the water-bearing unit beneath DDJC-Sharpe, probably as a result of the
28 reduction of ferric iron and manganese, respectively. In general the concentrations of

1 dissolved iron and manganese were relatively low; and there is no apparent spatial
2 association of these constituents with dissolved CAH or fuel hydrocarbons. The
3 anomalously high manganese concentration (42 mg/L) in the sample from well MW477A
4 suggests that conditions in groundwater at this location may be more highly reducing
5 than the measured ORP value (266.3 mV) might indicate. Reducing conditions at this
6 location are also suggested by the concentration of sulfate in the groundwater sample
7 from well MW477A – at 0.06 mg/L, the lowest concentration of sulfate detected during
8 July and August 2000.

9 Although reductive dehalogenation may occur under nitrate- and sulfate-reducing
10 conditions (Vogel *et al.*, 1987; Chapelle, 1996), the most rapid dehalogenation rates,
11 affecting the greatest variety of CAH, occur under methanogenic conditions (Bouwer,
12 1994). Methane was analyzed in groundwater samples collected by Radian (Radian,
13 1999b), to evaluate the potential for methanogenesis. Methane has been detected in
14 groundwater samples from three of the seven wells sampled during Radian's natural
15 attenuation evaluation (wells MW429A, MW477A, and MW517A), at concentrations
16 ranging from 14 µg/L (well MW429A) to 220 µg/L (well MW517A). The occurrence of
17 methane in groundwater samples from well MW477A provides further evidence of the
18 existence of reducing conditions in groundwater at this location.

19 **2.3.3.5 Alkalinity and pH**

20 In water-bearing units having carbonate minerals as part of the matrix, carbon dioxide
21 in groundwater forms carbonic acid, which dissolves these minerals and increases the
22 alkalinity of the groundwater. An increase in alkalinity in an area where CAH are present
23 in groundwater can be used to infer that hydrocarbon compounds (or native organic
24 carbon) have been degraded through aerobic and/or anaerobic microbial respiration.

25 Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused
26 by the addition of biologically-generated acids. The alkalinity values of the 42 wells
27 sampled at DDJC-Sharpe ranged from 70 mg/L at well MW522C to 1,500 mg/L at well
28 MW477A (Table 2.7), with most alkalinity values lower than about 400 mg/L. This
29 range of alkalinity is sufficient to buffer potential changes in pH caused by biologically

mediated reactions and suggests that aerobic and/or anaerobic biodegradation processes should not cause detrimental shifts in the pH of groundwater at DDJC-Sharpe. The neutral to slightly basic pH values measured in groundwater at the facility support this observation. No trends are apparent in the spatial distribution of alkalinity values, suggesting either that the degradation of dissolved CAH is proceeding at rates too low to generate significant quantities of carbonic acid, or that the carbonate content of the water-bearing strata is low, and little carbonate material is available for dissolution.

2.3.3.6 Estimation of Biodegradation Rates

Chemical degradation via biotic or abiotic mechanisms may be the most important process acting to remove chemical mass from the subsurface (Appendix B). Therefore, estimation of the rates of chemical degradation is necessary to properly evaluate the ultimate fate of TCE and its daughter products at DDJC-Sharpe. First-order degradation rate constants may be calculated using field data, or by using representative samples of the aquifer material and groundwater in microcosm studies (USEPA, 1998). Microcosms are most appropriate as indicators of the potential for natural bioremediation, and to evaluate whether losses of chemical mass are a result of biological activity, but it may be inappropriate to use them to generate rate constants. The preferred method of evaluating degradation rate constants is by use of field data.

A method for evaluating site-specific first-order rate constants for chemical degradation is described by USEPA (1998). The method, proposed by Buscheck and Alcantar (1995), is based on application of the one-dimensional, steady-state analytical solution to the advection-dispersion equation, and is used to examine the distribution of chemical concentrations in a contaminant plume, presumed to be at steady-state conditions. The method of Buscheck and Alcantar (1995) uses plume length and chemical concentrations along the plume centerline to calculate first-order decay rates.

Site-specific information required for calculations using the method of Buscheck and Alcantar includes:

- concentrations of primary compound and daughter product(s) at known distances downgradient from an identified source of chemicals,

- migration velocity of the primary compound and daughter products (the seepage velocity, incorporating chemical retardation), and
- longitudinal dispersivity.

The concentrations of TCE and (where available) *cis*-1,2-DCE, detected in groundwater samples collected during the same (or temporally juxtaposed) monitoring event(s), were used in calculations to estimate first-order degradation rate constants for TCE and *cis*-1,2-DCE along each of five flowpaths in the groundwater system at DDJC-Sharpe (Appendix B, Section B2.5.6). Because VC has only been sporadically detected in groundwater samples from DDJC-Sharpe, it was not possible to apply the method of Buscheck and Alcantar (1995) to evaluate VC degradation. The results of decay-rate calculations are described in detail in Appendix B and summarized in Table 2.9.

TABLE 2.9
FIRST-ORDER DEGRADATION RATE CONSTANTS
ESTIMATED FOR CAH IN GROUNDWATER^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

	CAH Constituent			
	TCE		<i>cis</i> -1,2-DCE	
	Rate Constant (day ⁻¹)	Half-life (years)	Rate Constant (day ⁻¹)	Half-life (years)
Maximum first-order rate constant	0.00014	14	0.00036	5
Minimum first-order rate constant	0.000024	80	0.000034	56
Median first-order rate constant	0.000095	20	0.00019	10
Literature values of first-order rate constants ^{b/}	0.0005	3.8	0.0005	3.8

^{a/} First-order degradation rates for chlorinated aliphatic hydrocarbon compounds (CAH) in groundwater at DDJC-Sharpe estimated using the method of Buscheck and Alcantar (1995), with concentrations of TCE and *cis*-1,2-DCE reported for historic groundwater sampling events. Methods and results of calculations are presented in Appendix B.

^{b/} Literature values for first-order rate constants (minimum values reported) from Wiedemeier *et al.* (1999).

The first-order rate constants for degradation of TCE and *cis*-1,2-DCE, calculated using the method of Buscheck and Alcantar (1995), are restricted to a fairly narrow range. First-order rate constants calculated for TCE ranged from 0.000024 per day (day⁻¹) to 0.00014 day⁻¹, with a median value of 0.000095 day⁻¹. These correspond to half-lives for TCE of about 80, 14, and 20 years, respectively (Table 2.9). First-order rate constants

1 calculated for *cis*-1,2-DCE ranged from 0.000034 day⁻¹ to 0.00036 day⁻¹, with a median
2 value of 0.00019 day⁻¹. These correspond to half-lives for *cis*-1,2-DCE of about 56, 5,
3 and 10 years, respectively. The similarity in the ranges of first-order degradation rate
4 constants for TCE and *cis*-1,2-DCE imply that DCE isomers are degraded to VC at
5 approximately the same rate that DCE is produced by the degradation of TCE. The
6 general absence of VC in groundwater samples further implies that VC, in turn, is
7 degraded as quickly as it is produced from the degradation of DCE isomers. It should be
8 noted that aerobic conditions in the subsurface favor the degradation of VC (Appendix
9 B); and that about one-half of the groundwater samples collected and analyzed during
10 July and August 2000 contained DO at concentrations greater than about 1 mg/L (Section
11 2.3.3.3; Table 2.7). A possible mechanism for complete mineralization of TCE at DDJC-
12 Sharpe could have TCE and DCE isomers reductively dechlorinated in more-reducing
13 parts of the groundwater system. The VC generated during reductive dechlorination
14 could then migrate to more aerobic parts of the system, and be degraded in turn.

15 The first-order rate constants, developed in the calculations, are representative of
16 ranges, reported for TCE and *cis*-1,2-DCE in the literature (Table 2.9; Anthony *et al.*,
17 1997; Dragun, 1988; Sivavec and Horney, 1995; Wilson *et al.*, 1994; Wiedemeier *et al.*,
18 1999). It must be recognized that, although some uncertainty is associated with these
19 estimates, the calculated degradation rates are consistent with current knowledge of the
20 occurrence of TCE and its daughter products, historically detected in groundwater
21 samples from DDJC-Sharpe.

22 **2.3.3.7 Conclusions**

23 The prevalence of reductive dehalogenation daughter products (e.g., *cis*-1,2-DCE)
24 within the TCE plume is an indication that biotransformation of TCE via reductive
25 dehalogenation may be occurring. DO concentrations were 1 mg/L or less in
26 approximately one-half of the 42 samples analyzed, indicating that conditions are
27 favorable for anaerobic dehalogenation reactions. Methane, an indicator of
28 methanogenesis, was detected in groundwater samples collected by Radian from three of
29 the seven wells monitored in conjunction with their natural attenuation evaluation,
30 including well MW477A. Thus it appears that local conditions in parts of the

groundwater system at DDJC-Sharpe are favorable for promoting the complete degradation of TCE to innocuous end products such as ethane and ethene.

TOC concentrations were 10 mg/L or less in 30 of the 42 samples that were collected. According to guidance documents (USEPA, 1998), dissolved organic carbon concentrations less than 20 mg/L may not constitute a source of carbon and energy sufficient to promote reductive dehalogenation. However, the prevalence of *cis*-1,2-DCE in groundwater samples suggests that the relatively low concentrations of TOC in groundwater may not be a significant limiting factor at DDJC-Sharpe.

2.4 SUMMARY OF REFINEMENTS TO CSM

The updated and refined CSM presented in the preceding sections has been based on review of available information and previously-published documents, new interpretation of available information by Parsons, and additional data collected in support of this RPO evaluation. The modifications and additions to the CSM developed by Parsons are summarized, and suggestions are provided for obtaining additional information in areas where additional refinement of the CSM for DDJC-Sharpe may be necessary.

2.4.1 Model Refinement

The primary elements of the refined CSM for DDJC-Sharpe are summarized as follow:

- Originally, the hydrogeologic system at DDJC-Sharpe was described in the RI (ESE, 1990) and ROD (ESE, 1993a) as consisting of four separate water-bearing zones (the “A”, “B”, “C”, and “D” zones). However, separate zones cannot be distinguished on the basis of their hydrogeologic characteristics, and do not appear to be separated hydraulically by areally extensive, low-permeability barriers. Furthermore, hydrologic observations, including migration of contaminants between different monitoring zones at some locations, and the propagation of hydraulic stresses through several monitoring zones during pumping tests, indicate that the monitoring zones are generally in hydraulic communication. Therefore, the complex hydrostratigraphic package of gravel, sand, silt, and clay that extends to a

1 depth of approximately 270 feet bgs at DDJC-Sharpe comprises a single,
2 heterogeneous water-bearing unit.

- 3 • The key hydraulic properties of various components of the water-bearing unit (e.g.,
4 transmissivity, hydraulic conductivity) have been presented in several documents
5 (e.g., ESE, 1990; ETA, 1993; USACE, 2000). In most cases, the reported ranges of
6 values for hydraulic properties are not consistent among the various sources, and
7 discussion regarding the derivation of hydraulic-property often is not presented.
8 Parsons reviewed the available data, selected the range(s) of values judged to be
9 most representative on the basis of interpretation and professional judgment,, and
10 summarized the results (Section 2.2.3 of this report). Re-interpretation of test
11 results (e.g., pumping tests) was not performed. The average linear velocity of
12 groundwater flow was also generated using available information (Section 2.2.3 of
13 the report).

- 14 • Clay strata below the water table have been described as “unsaturated” (ESE,
15 1990), on the basis of field observations of moisture content in drive samples and
16 cuttings. It is unlikely that earth materials located below the water table would
17 remain unsaturated for any length of time (Freeze and Cherry, 1979); therefore, in
18 the absence of laboratory data to substantiate this observation, it is probable that the
19 clays are saturated, but locally represent barriers to contaminant migration, as a
20 consequence of their low hydraulic conductivity. The hydraulic properties (in
21 particular, hydraulic conductivity) of the sandy strata are undoubtedly quite
22 different from the hydraulic properties of the fine-grained (clay) and silt units. As a
23 result of the contrasts in hydraulic properties, groundwater movement (and, hence,
24 migration of dissolved contaminants) preferentially occurs through sandier
25 intervals of the water-bearing unit. Contaminant migration also occurs through
26 finer-grained hydrostratigraphic intervals, but proceeds at much lower rates.

- 27 • The lateral and vertical distribution of VOCs in groundwater at DDJC-Sharpe is
28 highly variable due to a number of factors including:

- 29 1. existence of multiple potential source areas,

2. variability in the location, timing, and duration of contaminant releases in source areas,
3. changes in contaminant migration directions, resulting from temporal changes in horizontal and vertical hydraulic gradients,
4. changes in contaminant concentrations with increasing migration distance from source areas, resulting from attenuation mechanisms including dilution, dispersion, adsorption, and chemical reactions, and
5. heterogeneity of the subsurface materials leading to development of flow paths along which contaminant migration may preferentially occur.

- Eight separate and distinct dissolved CAH plumes originally were delineated in groundwater at DDJC-Sharpe (ESE, 1990). Multiple plumes, emanating from several sources, undoubtedly exist; however, it is not correct to characterize these plumes as “separate”, because extensive co-mingling has occurred during contaminant migration over a period of 30 to 40 years. Based on review of current conditions, it appears that a CAH plume originating in the South Balloon area has migrated in groundwater to the Central Area, and co-mingled with smaller plumes in the Central Area, to form a single, extensive, co-mingled plume (Figure 2.13). A single, smaller plume is associated with the North Balloon area.

- During the early phases of environmental investigations at DDJC-Sharpe, the highest concentrations of CAH were detected in groundwater of the “A” zone (ESE, 1993). TCE concentrations in the “A” zone subsequently have decreased overall (Radian, 2000a). Concentrations of CAH in groundwater of the “B” and “C” zones have decreased at some locations, and have increased at others. Currently the concentrations of CAH in groundwater of the “B” and “C” zones generally are higher than CAH concentrations in the “A” zone. This is could be due to several factors, including: 1) elimination or reduction of CAH migration from chemical sources in the vadose zone to the groundwater system; 2) removal of CAH mass from groundwater in the “A” zone via groundwater extraction and

1 natural attenuation mechanisms; or 3) migration of contaminants from the “A” zone
2 to deeper intervals in response downward-directed hydraulic gradients resulting
3 from the relatively greater rates of groundwater extraction in the “C” zone.

- 4 • To date, the nature of vertical migration of contaminants through the groundwater
5 system, and the mechanisms of contaminant migration along discrete pathways,
6 have not been seriously examined. Although historic monitoring of individual
7 zones has provided important information regarding hydrogeologic conditions and
8 the distribution of contaminants in the subsurface, the concept of four separate
9 horizons at DDJC-Sharpe, while appropriate for categorizing monitoring intervals,
10 has unfortunately contributed to the misconception that contaminant plumes occur
11 separately and behave differently within the four different “horizons” or water-
12 bearing units at the site. All interpretations of contaminant migration have
13 followed the concept of “horizons” to the extent that data evaluation, presentation
14 of results, and design and installation of extraction and monitoring wells installed at
15 DDJC-Sharpe have been horizon-specific. This approach may be contributing to
16 the piecemeal approach characteristic of groundwater remediation at DDJC-Sharpe.
17 By contrast, a comprehensive understanding of contaminant migration (c.f., Section
18 2.3.2.2 and Figures 2.1, 2.13, 2.14, and 2.15) could lead to the development of a
19 remediation approach that would address the entire extent of dissolved CAH in
20 groundwater at any given area. In retrospect, it appears that the horizon-specific
21 approach may have contributed to potential misinterpretations of the behavior of
22 dissolved CAH plumes, unnecessary monitoring and/or groundwater extraction,
23 and has certainly made data collection, analysis, and reporting a cumbersome
24 process.

- 25 • Biodegradation of CAH is occurring in groundwater at the North Balloon, South
26 Balloon, and Central Area; and is occurring in all depth intervals of the water-
27 bearing unit at DDJC-Sharpe (Section 2.3.3). Other natural attenuation
28 mechanisms, including dispersion, dilution, sorption, and volatilization also are
29 acting to reduce the mass, concentrations, and mobility of CAH contaminants in
30 groundwater. The rates of chemical degradation are sufficiently rapid that natural

attenuation should be considered as a supplement to active groundwater ETI remedies.

2.4.2 Recommendations for Additional Information

Reductive dehalogenation of CAH generally proceeds most effectively under anaerobic conditions (USEPA, 1998). While the concentrations of DO in groundwater are generally low across much of DDJC-Sharpe, elevated concentrations of DO (greater than 5 mg/L) occur in groundwater at some locations (Section 2.3.3.3; Table 2.7), and may inhibit degradation of the more highly chlorinated CAH (e.g., TCE). Operation of the groundwater ETI systems may be drawing oxygenated groundwater from areas outside of the dissolved CAH plumes at DDJC-Sharpe, thereby creating more aerobic conditions within the plumes, and decreasing the rates of CAH degradation. The extent to which this is occurring is not known, but has significant implications for improving the effectiveness of reductive dehalogenation processes. Furthermore, the most rapid dehalogenation rates, affecting the greatest variety of CAH, occur under methanogenic conditions. While the results of limited sampling indicate that methanogenesis is occurring (at least locally) in groundwater at DDJC-Sharpe (Section 2.3.3.4), the extent of methanogenesis, and the degree to which methanogenic processes are degrading CAH, are not known. In order to address these questions, Parsons suggests that groundwater samples, collected from a number of locations across the facility, and from locations off-facility and upgradient of CAH plumes, be analyzed for DO, ORP, and dissolved gases (methane, ethene, and ethane). Groundwater samples could be collected in conjunction with a comprehensive sampling event – for example, scheduled annual or semi-annual groundwater monitoring. The results of analyses of samples for DO, ORP, and dissolved gases would enable a more detailed and complete evaluation to be made of geochemical conditions in the subsurface at DDJC-Sharpe.

2.5 ALTERNATIVE FORMAT FOR DATA PRESENTATION

Radian currently provides detailed analyses of groundwater monitoring results in the FFA annual monitoring reports (e.g., Radian, 1999g). The evolution of contaminant plumes typically are reviewed in the annual reports only for the most recent 12-month period. However, interpretations of plume continuity and stability can be affected by

1 variations in well density (horizontally and vertically in space) and in the wells sampled
2 during a given monitoring event, presentation of contaminant occurrence by horizon, and
3 incorporation of diluted COC concentrations measured at extraction wells into the
4 evaluation. Interpolations of plume continuity between widely spaced wells appear to be
5 based in part on results of historical (pre-1999) sampling events, compiled and
6 considered together with more recent monitoring results. The TCE plumes depicted on
7 Figures 2.9 through and 2.12 are examples from the 1999 annual groundwater monitoring
8 report (Radian, 1999g).

9 Because the separate “monitoring zones” actually comprise different depth intervals
10 within the same, hydraulically-interconnected, water-bearing unit, a more representative
11 depiction of the lateral extent of TCE in groundwater throughout the entire water-bearing
12 unit can be generated by considering all of the results of a single monitoring event
13 together, rather than grouping the results by groundwater monitoring zone. Using this
14 techniques, Parsons developed a series of thematic concentration maps for TCE in
15 groundwater, to better illustrate the evolution of plumes (and the groundwater monitoring
16 program) over time, and to demonstrate the impact of sampling design on interpretations
17 of plume configurations and migration.

18 Maps were generated using all analytical data for TCE included in the electronic
19 database for the time periods selected. To provide insight into historical sampling
20 programs and plume interpretation, figures showing distributions of TCE in groundwater
21 within all horizons for 1990 (prior to startup of groundwater ETI systems in the North
22 Balloon and Central Area; Figure 2.16), 1993 (Figure 2.22), 1995 (Figure 2.23), 1997
23 (Figure 2.24), and 1999 (Figure 2.13).

24 On each figure, only wells sampled during the monitoring event(s) represented are
25 depicted, allowing the reader to readily apprehend changes in sampling design among
26 monitoring events. The concentration of TCE, presented thematically at each monitoring
27 point indicated on the Figures, is the highest concentration detected in groundwater from
28 an individual well within a well cluster at a particular location, regardless of the depth
29 interval from which the sample was collected. The maximum concentration of TCE

1

2 **Figure 2.22 TCE Concentrations in Groundwater --1993**

3 (Oversize 11 x 17)

4

1 **Figure 2.23 TCE Concentrations in Groundwater -- 1995**

2 (Oversize 11 x 17)

3

1 **Figure 2.24 TCE Concentrations in Groundwater -- 1997**

2 (Oversize 11 x 17)

3

1 detected at each location during the sampling period is represented thematically using a
2 colored symbol to indicate TCE concentration intervals ranging from less than 0.5 µg/L
3 to greater than 25 µg/L. Using thematic displays, chemical concentrations are associated
4 with the appropriate monitoring locations, and the basis for the contaminant magnitudes
5 and distributions is linked directly to the electronic data base.

6 Comparison of the information presented on the figures shows the variability of
7 sampling locations through time, as characterization of the TCE plumes progressed and
8 LTM wells were established. Thematic presentation also allows ready identification of
9 persistent hot spots, in addition to areas where TCE concentrations have decreased. If
10 TCE isoconcentration contours were to be generated, the basis for (and reliability of) the
11 contouring would be readily apparent to reviewers, thereby minimizing the potential for
12 misinterpretation of plume extent (and contaminant migration) resulting from changes in
13 the spatial density of sample collection. Furthermore, this method of data presentation is
14 flexible, and can accommodate a wide range of reporting variables (e.g., individual
15 sampling events, all events within a specified period of time, discrete horizons or zones,
16 discrete analytes, concentrations ranges of particular interest, etc.), and is potentially a
17 valuable tool for interpretation of hydrologic and chemical conditions, and for continued
18 optimization of the groundwater ETI and monitoring systems.

SECTION 3

EVALUATION OF REMEDIATION GOALS

Developing a clear understanding of the goals and objectives of an environmental remediation project is an essential element of the RPO process. The RPO evaluation presents an opportunity to review the RAOs and cleanup goals for DDJC-Sharpe, and to provide input regarding these goals to the continuing dialogue with regulatory officials responsible for oversight of remediation activities. As site information is updated, new opportunities may arise to recommend and justify revision of monitoring requirements, cleanup goals, and/or treatment processes during 5-year ROD reviews. The RPO Phase II evaluation also provides an opportunity to reassess whether the remedial alternatives that have been implemented (or are pending) in accordance with the terms of the RODs at the facility and continue to be the most appropriate and effective alternatives available in light of technological improvements, refinement of the CSM, and/or changes in the regulatory framework, and to consider modifications to the remedial actions/systems that may enhance the effectiveness of the selected remedies.

3.1 RAOS AND ROD CLEANUP GOALS

DDJC-Sharpe is listed on the National Priorities List (NPL), and the environmental restoration program is being implemented in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), with regulatory oversight provided by USEPA Region 9 and the State of California. Pursuant to Section 121(d) of CERCLA, as amended (USEPA, 1986a), remedial actions must attain a degree of cleanup that assures protection of human health and the environment. RAOs are established in the DDJC-Sharpe RODs to define the objectives of the selected remedies for contaminants in soil and groundwater.

CERCLA requires compliance with applicable or relevant and appropriate requirements (ARARs). Chemical- and action-specific ARARs for contaminants in

groundwater and treatment-plant effluent at DDJC-Sharpe are specified as aquifer cleanup levels (ACLs) in the two RODs and as discharge requirements in the Waste Discharge Requirement (WDR) Order (Central Valley RWQCB, 1995). ROD cleanup goals for soil are based on ARARs for protection of underlying groundwater, are risk-based, or are based on other criteria to-be-considered (TBCs). Rules promulgated by the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) represent action-specific ARARs applicable to the discharge of vapor emissions from operating SVE systems, and from stripping towers at the groundwater treatment plants, to the atmosphere. No location-specific ARARs have been identified for DDJC-Sharpe (ESE, 1993a; ESE, 1996).

In accordance with the provisions of CERCLA, a ROD documents the regulatory decisions, made with public input, regarding remediation of a site in compliance with ARARs and TBCs. In order to modify ROD-specified cleanup goals or discharge requirements for DDJC-Sharpe, a convincing argument, based on technological and/or scientific data, must be made to persuade regulatory authorities that a ROD amendment is warranted. If such an argument can be made, the terms of the ROD can be modified through either an explanation of significant difference (ESD) or an amendment to the ROD. Based on the results of this RPO evaluation and ongoing work at DDJC-Sharpe performed by Radian, revision of the ACLs for groundwater is not recommended at this time. However, revision of soil-vapor cleanup goals for TCE, specified in the Basewide ROD (ESE, 1996), may be appropriate (Section 3.3).

3.1.1 Contaminants in Soil

Contaminated soils at DDJC-Sharpe have been designated as OU2. As discussed in Section 2.3.1, available data indicate that VOCs are present in soils in the South Balloon and Central Areas at DDJC-Sharpe, and that sources of VOCs may include former disposal sites/burial trenches at several different locations. The concentrations of metals that have been detected in soils may be naturally-occurring, or may comprise some degree of anthropogenic metals contamination. Several sites in the North Balloon and South Balloon areas were identified as areas where near-surface soils (at depths less than 2 feet below ground surface [bgs]) contained elevated concentrations of metals.

In 1994, ESE (1994b) prepared a Risk Assessment (RA) report, addressing possible human-health and ecological risks associated with contaminants in soils at DDJC-Sharpe. The RA identified on-site workers, together with resident army personnel and their families, as the human receptors at the installation that could potentially be exposed to contaminants in soils, and provided a quantitative evaluation of the potential risks to these receptors. In addition, ecological impacts associated with soil contamination at the site were evaluated in the RA. Lead, chromium, chlordane, dieldrin, p,p'-dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), and DDT were identified as COCs in soil based on the results of risk characterizations completed for human and ecological receptors (ESE, 1996).

3.1.1.1 Cleanup Goals for Contaminants in Soil

Cleanup goals for lead, chromium, and TCE in soil, established in the ROD for OU2 (ESE, 1996), are presented in Table 3.1. Cleanup goals for pesticides (e.g., chlordane, dieldrin, DDD, DDE, and DDT) were not included in the ROD for OU2, because pesticide-contaminated soils were excavated from the areas in which pesticides had been detected, and were disposed at an appropriately-licensed off-site facility (ESE, 1996), prior to promulgation of the ROD.

TABLE 3.1
CLEANUP GOALS FOR SOILS IN OPERABLE UNIT 2^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Chemical of Concern	Cleanup Goal	Basis for Establishing Cleanup Goal
Chromium	300 mg/kg ^{b/}	Central Valley RWQCB request
Lead	1,000 mg/kg	Results of Human Health Risk Assessment (exposure of industrial worker)
TCE	350 ppbv ^{c/} (in soil vapor)	Calculated concentration of TCE in soil vapor that will not produce concentrations of TCE in underlying groundwater that exceed the MCL for TCE (5 µg/L ^{d/})

^{a/} Cleanup goals for soil were established in the Basewide ROD for OU2 (ESE, 1996).

^{b/} mg/kg = milligrams per kilogram.

^{c/} ppbv = parts per billion (by volume).

^{d/} µg/L = micrograms per liter.

A cleanup goal of 300 mg/kg for chromium in soil was established at the request of the Central Valley RWQCB (ESE, 1996), based on the potential for adverse impacts that might result from migration of dissolved chromium to groundwater.

A cleanup goal of 1,000 mg/kg, developed for lead in soil at the North and South Balloon Areas (Table 3.1), represents the maximum concentration of lead that could remain in soil while being protective of industrial workers that might be exposed to lead in soil at the installation. Although this cleanup level for lead in soil may not be protective of a child resident (ESE, 1996), exposure of children is not likely to occur at lead-contaminated areas of DDJC-Sharpe.

Although TCE was not identified in the RA report (ESE, 1994b) as a COC in soil, a cleanup goal for TCE in soil vapor was established in the ROD for OU2 (ESE, 1996), based on consideration of vapor-phase concentrations of TCE in soil judged to be protective of groundwater. The cleanup goal for TCE in soil vapor was based on a calculated concentration of TCE in soil vapor, in equilibrium with concentrations of TCE sorbed to soil or dissolved in soil water in the vadose zone, that will not produce dissolved-phase concentrations of TCE that exceed the maximum contaminant level (MCL) in groundwater underlying areas of soil that contains TCE. The conditions of the ROD for OU2 (ESE, 1996) allow periodic re-evaluation of the cleanup goals for TCE in soil.

3.1.1.2 Remedial Measures for Soil

The selected remedies identified in the ROD for OU2 (ESE, 1996) included removal of lead- and chromium-contaminated soils in the surface and near-surface, and disposal at an offsite landfill; *in-situ* volatilization and SVE of TCE-contaminated soils at seven locations, and NFA at 111 SWMUs representing areas where conditions were determined to pose no current or potential future threat to human health or the environment. After the ROD was issued in 1996, areas having elevated concentrations of VOCs in soil vapor were further characterized; and the concentrations of TCE in soil vapor at five sites – sites P-1A, P-1B, P-1C, and P-1E, in the South Balloon area, and site P-6A, in the Central Area - exceeded the cleanup standard of 350 ppbv of TCE (Section 2.3.1.2). In

accordance with the requirements of the ROD for OU2, SVE systems were subsequently designed and installed at these five sites (Radian, 1997c), and have been in operation since the third quarter of 1998 (Radian, 1999g). The SVE systems operating at DDJC-Sharpe are discussed in detail in Section 4.1.

Removal actions for lead- and chromium-contaminated soils at sites S-3 and S-26, were completed in 1998 (Section 2.3.1.1).

3.1.2 Contaminants in Groundwater

Remedial investigations were conducted at DDJC-Sharpe between 1982 and 1989 to evaluate the nature and extent of site-related contaminants in groundwater at the facility (Sections 1.4.2 and 2.3.2). The primary contaminants identified in groundwater at DDJC-Sharpe include VOCs, arsenic, selenium, nitrates, and bromacil. The extent and concentrations of these contaminants vary, depending upon location at the facility (Sections 2.3.2 and 2.4.1). TCE historically has been the VOC most frequently detected in groundwater, has been detected at the highest concentrations, and is regarded as the primary COC in groundwater. Based on the results of the RI, two groundwater extraction and treatment systems were installed as interim remedial measures to limit the further migration of contaminated groundwater. One system began operation at the South Balloon Area in March 1987, and the second system began operation at the North Balloon Area in October 1990.

In 1991, ESE prepared an RA report (ESE, 1991b), addressing conditions in groundwater at DDJC-Sharpe. Although human and ecological receptors are not exposed to contaminated groundwater under current land-use conditions, it was determined that ecological receptors could potentially be exposed to contaminated groundwater in off-site irrigation wells under future land-use conditions (ESE, 1991b). However, the potential risks resulting from this exposure pathway were considered to be negligible, in view of the volatility and relatively low concentrations of the more toxic contaminants (primarily VOCs), and ecological risks were not further evaluated.

A quantitative evaluation of the potential risks to future on-site and off-site human receptors exposed to groundwater also was completed, assuming that potable

groundwater wells could be installed at the facility at some future time, or that contaminants in groundwater could migrate off-site to the potable water wells nearest DDJC-Sharpe, approximately 2,000 feet west of the facility boundary. The RA results indicated that potential future risks were associated primarily with ingestion of arsenic and TCE in drinking water.

The results of the FS (ESE, 1991a) and the RA (ESE, 1991b) for VOCs, arsenic, selenium, nitrate, and bromacil in groundwater were summarized in the ROD for OU1 (ESE, 1993a). In accordance with the requirements of the ROD, (ESE, 1993a), groundwater contaminated with constituents other than VOCs, arsenic, selenium, nitrate, and bromacil, or constituents identified in future investigations, would be addressed in a separate Site-wide comprehensive ROD. Prior to the promulgation of the ROD for OU1, a third groundwater extraction and treatment system was designed and installed at DDJC-Sharpe, in the Central Area. The Central Area system began operation in May 1995.

3.1.2.1 Cleanup Goals for Contaminants in Groundwater

Pursuant to State Water Resources Control Board Resolution 88-63 and the California Porter-Cologne Water Quality Act, the California RWQCB (1998) Central Valley Basin Plan classifies OU1 water-bearing units as having "existing or potential beneficial uses as sources of drinking water"(California RWQCB, 1998). Therefore, the chemical-specific ARARs for OU1 aquifer restoration are federal drinking water standards, or standards promulgated by the State of California that are more stringent than federal standards. The ACL concentrations for OU1 groundwater at DDJC-Sharpe are summarized in Table 3.2.

TCE was identified in the ROD (ESE, 1993a) as the COC in groundwater at the facility, having the greatest associated health-based risk. Two different ACLs for TCE were considered:

1. Concentrations of TCE in groundwater, ranging from 0.18 µg/L to 1.98 µg/L, calculated to produce excess cancer risks of one in one million (1×10^{-6}), based on exposure of hypothetical future on-site residents to TCE in groundwater via all exposure routes; and

TABLE 3.2
AQUIFER CLEANUP LEVELS FOR OPERABLE UNIT 1 GROUNDWATER^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Chemical of Concern	Aquifer Cleanup Level (µg/L) ^{b/}	Basis for Establishing Cleanup Level
Benzene	NA ^{c/}	Human Health Risk Assessment ^{d/}
Bromacil	NA	NA
Bromodichloromethane	0.5	Human Health Risk Assessment
Bromoform	0.5	Human Health Risk Assessment
Carbon Tetrachloride	0.5	Human Health Risk Assessment
Chloroform	0.5	Human Health Risk Assessment
Dibromochloromethane	0.5	Human Health Risk Assessment
1,2-Dichlorobenzene	10	California Action Level
1,4-Dichlorobenzene	5	California Primary MCL ^{e/}
1,1-Dichloroethane	5	California Primary MCL
1,2-Dichloroethane	0.5	Human Health Risk Assessment
1,1-Dichloroethene	0.5	Human Health Risk Assessment
<i>cis</i> -1,2-Dichloroethene	6	California Primary MCL
<i>trans</i> -1,2-Dichloroethene	10	California Primary MCL
1,2-Dichloropropane	0.5	Human Health Risk Assessment
1,3-Dichloropropene	0.5	Human Health Risk Assessment
Ethylbenzene	NA	NA
Methylene Chloride	0.5	Human Health Risk Assessment
1,1,1-Trichloroethane	200	California Primary MCL
1,1,2-Trichloroethane	0.5	Human Health Risk Assessment
1,1,2,2-Tetrachloroethane	0.5	Human Health Risk Assessment
Tetrachloroethene	0.5	Human Health Risk Assessment
Trichloroethene	5	USEPA and California Primary MCL
Toluene	NA	NA
Vinyl Chloride	0.5	Human Health Risk Assessment
Xylene Isomers (total)	NA	NA

^{a/} Treatment standards and aquifer cleanup levels for groundwater established in the ROD for OU1 (ESE, 1993a).

^{b/} µg/L = micrograms per liter.

^{c/} NA indicates aquifer cleanup levels regulated under a separate order adopted by the Central Valley RWQCB because the constituents are not hazardous substances under CERCLA, as determined by USEPA and the State of California.

^{d/} Human health risk assessment was completed in conjunction with the remedial investigation for DDJC-Sharpe OU 1 (ESE, 1991b), and the results were reported in the OU1 ROD (ESE, 1993a).

^{e/} MCL = maximum contaminant level.

2. A concentration of 5 µg/L of TCE in groundwater, based on the MCL for TCE in drinking water (Section 1412 of the Safe Drinking Water Act, 42 USC 300 (g)(1), National Primary Drinking Water Regulations, 40 CFR Part 141).

According to the ROD, ACL concentrations of TCE in groundwater based on a target excess cancer risk level of 1×10^{-6} would be “too stringent” because groundwater at DDJC-Sharpe is not used as a drinking-water supply. Based on this determination, the MCL for TCE (5 µg/L) was selected as the ACL concentration for TCE in groundwater (Table 3.2). It should be noted that MCL concentrations are considered to be protective of residents consuming drinking water from public water supplies. Therefore, identification of the MCL concentration as the ACL for TCE in groundwater is consistent with the goal of restoring groundwater beneath DDJC-Sharpe to drinking-water quality.

ACL concentrations for 1,1-DCA, 1,2-DCB, 1,4-DCB, *cis*-1,2-DCE, *trans*-1,2-DCE, and 1,1,1-TCA in groundwater also were established in the ROD (Table 3.2). ACL concentrations for other identified carcinogenic constituents were established as “below detection limits” (0.5 µg/L). Cleanup goals were not established for benzene, bromacil, ethylbenzene, toluene, or xylene isomers in groundwater. As noted in the ROD, ACL concentrations for these constituents may be established under a separate order adopted by the Central Valley RWQCB, because the constituents are not CERCLA hazardous substances as determined by USEPA and the State of California.

3.1.2.2 Remedial Measures for Groundwater

Groundwater extraction and air-stripping treatment of extracted groundwater was selected as the most appropriate remedy for DDJC-Sharpe, and is discussed in detail in Section 4.2. The primary RAO for groundwater at DDJC-Sharpe is to restore groundwater to its highest beneficial use. However, according to the ROD (ESE, 1993a), USEPA and the State of California recognize that the selected groundwater ETI remedy may not be successful in reaching the cleanup goals established for groundwater. Therefore, if, during implementation or operation of the system, it becomes apparent that contaminant levels have ceased to decline and are remaining constant at levels higher

than the ACL concentrations established in the ROD, the RAOs and remedy selection may be re-evaluated.

3.1.3 Treatment of Vapor Effluent from SVE Systems

Action-specific ARARs include restrictions that define acceptable treatment and disposal procedures for waste streams from remedial actions and for hazardous substances. SVE systems are designed to remove volatile constituents from soils in the vadose zone; and as a consequence of their operation, such systems generate a vapor-phase effluent stream containing volatilized contaminants. In California, SVE effluent streams are subject to regulation under the Clean Air Act, as amended, the Resource Conservation and Recovery Act (RCRA), California statutes, and local Air Pollution Control District (APCD) regulations. At DDJC-Sharpe, air-discharge regulation is under the supervision of the SJVUAPCD, and operation of SVE units and vapor-treatment system is in accordance with rules promulgated by this agency. The District does not have prohibitory rules that would apply to remedial activities at DDJC-Sharpe; however, certain provisions in SJVUAPCD Rules 2201, 4651, and 4661 may apply to SVE effluent streams generated during soil remediation at the facility.

Rule 2201, the New and Modified Stationary Source Review Rule, regulates nonvehicular sources of air contaminants in California. The local APCD establishes allowable emissions limits. According to Rule 2201, a vapor effluent stream must be treated prior to discharge to the atmosphere, using best available control technology (BACT) if emissions of a regulated air contaminant exceed two pounds per day (lbs/day).

Rule 4651 regulates VOC emissions from soil decontamination activities. According to Rule 4651, *in-situ* treatment methods for contaminated soil (e.g., SVE systems) shall incorporate a VOC collection and control system. However, remediation of contaminated soil at sites affected by accidental spillage of less than one barrel (42 U.S. gallons) of liquids containing VOCs is not subject to the requirements of Rule 4651.

Rule 4661 regulates VOC emissions resulting from use or spillage of organic solvents. TCE and similar other solvent constituents are defined to be photochemically reactive solvents, and as such VOC emissions from these substances, (possibly including SVE

remediation activities at DDJC-Sharpe), are regulated in accordance with the requirements of Rule 4661. An operator discharging more than 40 pounds of VOC emissions per day from a source operation is required to install and operate a VOC emissions control device having an overall capture and control efficiency of at least 85 percent. PCE is defined (Rules 4661 and 1020) as “not a VOC”.

As a matter of policy, the SJVUAPCD performs a screening-level health risk assessment for air emissions resulting from soil or groundwater remediation projects. Radian (1997a) provided SJVUAPCD with relevant SVE system design information, including vapor-phase concentrations of contaminants and vapor flow rates, so that the contaminant loadings in the treated and untreated effluent streams could be estimated. The SVE systems to be operated at DDJC-Sharpe were designed to be equipped with granular activated carbon (GAC) filtration units to treat the SVE effluent vapor stream, in accordance with Rule 2201 (ESE, 1996; Radian, 1997c). For design purposes, and for the screening-level health risk assessment, the contaminant removal efficiency of the GAC treatment system was assumed to be 50 percent. The mass of all VOCs, including chlorinated and non-chlorinated solvents, fuel constituents, alcohols, and ketones, annually produced by operation of the SVE systems was calculated for sites P-1A/P-1B/P-1C, P-1E, and P-6A. The mass of VOCs remaining in the effluent stream after treatment and discharged to the atmosphere was also calculated. Radian (1997a) estimated that an SVE system operating continuously at site P-1A/P-1B/P-1C would produce a total of about 133 pounds of VOC mass per year (about 0.4 pounds per day); an SVE system operating continuously at site P-1E would produce a total of about 21 pounds of VOC mass per year (about 0.06 pounds per day); and an SVE system operating continuously at site P-6A would produce a total of about 78 pounds of VOC mass per year (about 0.2 pounds per day). Treatment of the effluent vapor streams by passing them through a GAC system (50 percent efficiency) would result in removal of one-half the VOC mass produced by the SVE systems.

Because the concentrations of all VOCs in soil vapor at DDJC-Sharpe are extremely low, the estimated emissions of most VOCs in effluent vapor were less than one pound per year, and the calculated impacts to public health from SVE sources at DDJC-Sharpe

were far below levels of concern (Radian, 1997a). In fact, with the exception of emissions of vapor-phase DCA, PCE, TCE and carbon tetrachloride, air concentrations calculated at the point of emission were below applicable reference exposure levels, and exposures at the facility boundary were far below these levels. Accordingly, no adverse impacts to public health were anticipated as a consequence of operation of the SVE systems. However, despite the low concentrations of volatile COCs anticipated in untreated vapor effluent from the SVE wells, and despite the fact that total COC mass in untreated effluent was unlikely to exceed the 2-pound daily limit established in Rule 2201, when the SVE systems went on-line in the third quarter of 1998, they were equipped with GAC canisters to treat the effluent vapor, prior to discharge to the atmosphere. Additional details regarding the SVE systems and vapor-treatment unit are provided in Section 4.1.

3.1.4 Groundwater Treatment Plant Effluent Discharge Requirements

Currently, three independently functioning groundwater extraction and treatment systems are in operation at DDJC-Sharpe. Several discharge options are available for treated effluent from the groundwater treatment plants (GWTPs):

- discharge to storm drains for conveyance and ultimate discharge to a surface-water receiving body;
- discharge to percolation ponds, with subsequent evaporation or infiltration to groundwater;
- re-introduction to groundwater in the saturated zone via injection wells; and
- offsite re-use.

The quality of treated water discharged from the GWTPs at DDJC-Sharpe to the SSJIDC, which drains into French Slough, is regulated under WDRs Order No. 95-258, National Pollution Discharge Elimination System (NPDES) permit No. CA0081931, adopted by the Central Valley RWQCB in December 1995. Under the terms of the NPDES permit, federal MCLs and RWQCB criteria were selected as effluent standards

(upper section of Table 3.3) to protect the existing or potential beneficial uses of the surface waters of the State of California (i.e., at French Slough).

Because treatment plant effluent can also be discharged to groundwater, cleanup standards for GWTP effluent routed to re-injection wells and percolation ponds for reintroduction to the water-bearing unit are based on preserving the highest potential beneficial use of groundwater. Accordingly, federal and state MCLs and more-stringent RWQCB criteria, based on discharge of effluent to land, were established as the standards for discharge of treated effluent (lower section of Table 3.3). In recognition that some of the constituents in the effluent stream may be present under natural conditions (e.g., arsenic, selenium, and nitrate), concentrations of these constituents representative of naturally-occurring (or “background”) conditions (Section 2.3.2.3) are allowable in the effluent discharge standards.

3.2 SITE-SPECIFIC SOIL CLEANUP GOALS FOR SITES P-1A,B,C, P-1E, AND P-6A

Releases of chemicals at several sites at DDJC-Sharpe have introduced VOCs to soils and groundwater in the vicinity, at concentrations that exceed cleanup goals established for these media in the DDJC-Sharpe RODs (ESE, 1993a; *ibid.*, 1996). The primary COC in soils at these sites is TCE. The concentrations of TCE in soil vapor at five sites – sites P-1A, P-1B, P-1C, and P-1E, in the South Balloon area, and site P-6A, in the Central Area (Figure 3.1) - exceeded the cleanup standard of 350 ppbv of TCE, established in the ROD for soils (ESE, 1996). The remedies selected for sites P-1A, P-1B, P-1C, P-1E, and P-6A involve installation, operation, and monitoring of SVE systems to treat soils contaminated with VOCs. Radian (1997a; *ibid.*, 1997b) has designed and is operating SVE systems at the five sites to remediate soils in the vadose zone to meet the soil-vapor cleanup criterion.

As specified in the final Base-Wide ROD (ESE, 1996), the objective of the SVE systems in operation at sites P-1A, P-1B, P-1C, P-1E, and P-6A, is to prevent further degradation of groundwater quality that could result from continued migration of TCE from vadose-zone soils to groundwater at dissolved concentrations exceeding the groundwater cleanup goals for TCE, specified in the ROD for OU1.

TABLE 3.3
EFFLUENT DISCHARGE STANDARDS FOR TREATED WATER^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Constituent	Daily Maximum Concentration (µg/L) ^{b/}	Weekly Average Concentration (µg/L)	Monthly Median Concentration (µg/L)
NPDES Effluent Limits for Discharge to South San Joaquin Irrigation District Canal			
Arsenic	50	- ^{c/}	40
Chromium	-	-	11
Lead	-	3.2	5.3 ^{d/} /3.2 ^{e/}
Mercury	2.4	-	0.012
Total Volatile Organic Compounds	1	-	< 0.5
Total Petroleum Hydrocarbons	100	-	< 0.5
Substantive Waste Discharge Requirements for Discharge of Effluent to Land^{f/}			
Arsenic	5 or background	-	-
Nitrate	10 or background	-	-
Selenium	5 or background	-	-
Benzene	1	-	0.5
Total BTEX ^{g/}	5	-	0.5
Bromacil	90	-	90
Tetrachloroethene	1	-	0.5
Trichloroethene	1	-	0.5
Total Volatile Constituents	5	-	1

^{a/} Discharge limitations for treated groundwater established in the ROD for OU1 (ESE, 1993a) and in the NPDES permit.

^{b/} µg/L = micrograms per liter.

^{c/} A dash (-) indicates that an effluent discharge limitation has not been established.

^{d/} 4-day average based on hardness of 200 mg of calcium carbonate per liter of receiving water.

^{e/} 4-day average based on hardness of 100 mg of calcium carbonate per liter of receiving water.

^{f/} Waste discharge requirements apply to treated waters discharged to injection wells or percolation ponds for reintroduction to A-Zone groundwater.

^{g/} BTEX = benzene, toluene, ethylbenzene, and xylene isomers.

Figure 3.1 Locations of Soil-Vapor Extraction Sites

The soil-vapor cleanup level of 350 ppbv for TCE apparently was derived on the basis of Henry's Law, which describes the concentration of a substance dissolved in the aqueous phase at equilibrium with its vapor phase (Appendix C). Several assumptions are necessary if vapor-phase concentrations of TCE, in equilibrium with concentrations of 5 µg/L of TCE dissolved in water, are to be established as the cleanup standard for TCE in soil vapor:

1. Soil vapor, containing TCE at a concentration of 350 ppbv, is in direct contact with the underlying water table, and remains in contact with groundwater until equilibrium concentrations are established.
2. Soil vapor, containing TCE at a concentration of 350 ppbv, is in direct contact with the water table across the entire affected area, and movement of groundwater into or out of the affected area does not occur. This assumption disallows the possibility that dilution of groundwater contaminated with TCE could reduce the concentrations of TCE to levels below the MCL concentration.
3. Upward migration of vapor-phase TCE toward the atmosphere (and away from the water table) does not occur. This is equivalent to stating that the concentrations of TCE are uniform throughout some thickness of the vadose zone, and remain constant through time.
4. If TCE in soil vapor is not in direct contact with groundwater in the saturated zone, but only is in contact with soil water in the unsaturated zone at some distance above the water table, equilibrium conditions will be established between TCE in the vapor phase, and TCE dissolved in soil water. TCE dissolved in soil water will then migrate to the water table (at whatever depth in the soil column below the contaminated soil vapor) with no attenuation occurring.

Vertically-upward migration of TCE in soil vapor is known to occur (TCE is a "volatile" organic chemical); and several different attenuation mechanisms, including volatilization, sorption to soil, dilution, dispersion, and chemical or biological

degradation, are capable of acting to reduce the mobility or concentrations of chemicals (including TCE) in the subsurface environment (USEPA, 1998). In light of these observations, the assumptions used to establish the cleanup standards for TCE in soil vapor appear to be overly conservative. Accordingly, the cleanup standards for TCE in soil vapor, established in the ROD, were reviewed, considering the current understanding of site-specific conditions in the subsurface at DDJC-Sharpe, to evaluate whether more realistic cleanup standards for TCE in soil vapor could be developed, that would still be protective of underlying groundwater.

Site-specific information was used to evaluate the potential for migration of TCE downward through the vadose zone to the water table, in order to predict the maximum concentrations of TCE that could remain in the vadose zone at each of the five sites without causing further migration at concentrations that would exceed the ROD ACLs (Appendix C). (Because sites P-1A, P-1B, and P-1C are in close proximity [Figure 3.1], and conditions at the three sites are similar, sites P-1A, P-1B, and P-1C were treated as a single site in the evaluation.) The results of this evaluation then were used to calculate the concentrations of TCE in the vapor phase, in equilibrium with the maximum concentrations of TCE that could remain in the soil column within the vadose zone. These calculated vapor-phase concentrations of TCE represent a convenient screening-level indicator of cleanup criteria for TCE in soil at the sites. If vapor-phase concentrations of a TCE at a particular location exceed the screening-level soil-vapor cleanup criterion developed for TCE at that location, then it is likely that the concentrations of TCE, in the sorbed, dissolved, and vapor phases in the vadose zone, are sufficiently elevated that TCE will continue to migrate to the groundwater table at concentrations that would exceed the ACL for TCE. Conversely, if vapor-phase concentrations of TCE are below the screening-level soil-vapor cleanup criterion for TCE at a particular location, then continued migration of TCE to the groundwater table at concentrations that would exceed the MCL is unlikely to occur.

Because the vadose zone at DDJC-Sharpe is unsaturated (i.e., pore spaces are not completely filled with water), an analytical solution to the one-dimensional (1-D), unsaturated-soil transport equation (Jury *et al.*, 1983) was used to evaluate the potential

migration of VOCs in the subsurface (Appendix C). Using the “Jury model”, chemical migration in the aqueous phase can be examined, and because the soil column simulated by the model contains some proportion of air in the pore spaces, vapor-phase transport also is accounted for. The solution to the equations describing 1-D, unsaturated transport (Jury *et al.*, 1983) is in the form of a partitioning model that distributes a chemical species in equilibrium among three of its possible phases (dissolved in the aqueous phase, sorbed to soil, and in soil vapor) in accordance with its chemical properties and local conditions in the subsurface.

In applying the model (Appendix C), the initial concentrations of TCE in the simulated vadose zone at each of the sites were adjusted until the maximum concentration of TCE calculated to arrive at the water table through the entire simulated time period did not exceed the ACL for TCE. Those initial concentrations represent the maximum concentrations of TCE that could remain in the vadose zone at a particular site without representing a threat to groundwater quality (Table 3.4, Column 3). The vapor-phase concentrations of TCE in equilibrium with the maximum allowable sorbed and dissolved concentrations in the vadose zone were then calculated using the Jury model. These vapor-phase concentrations are equivalent to screening-level soil cleanup criteria (Table 3.4, Column 4), in that they can serve to indicate whether TCE remaining in soil in the vadose zone is present at concentrations that could eventually cause chemical migration to the water table at concentrations that would exceed the ACL for TCE in groundwater (Table 3.4, Column 5).

The results of simulations indicate that if the vapor-phase concentration of TCE in soil vapor at sites P-1A/P-1B/P-1C is reduced to 620 ppbv, TCE is unlikely to continue to migrate from the vadose zone to the water table at concentrations that exceed the ACL for TCE (Table 3.4). The results of simulations also were used to derive screening-level soil cleanup criteria for TCE in soil vapor at the other two sites at DDJC-Sharpe (Table 3.4).

TABLE 3.4
SITE-SPECIFIC SOIL CLEANUP CRITERIA BASED ON
CONTAMINANT CONCENTRATIONS IN SOIL VAPOR
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Chemical of Concern ^{b/}	Maximum Concentrations Remaining in Vadose-Zone Soils ^{a/}		Maximum Dissolved Concentrations Migrating to Groundwater at the Water Table (µg/L) ^{e/}
		Sorbed Concentrations (µg/kg) ^{c/}	Resulting Equilibrium Concentrations in Soil Vapor/ Soil Cleanup Criterion (ppbv) ^{d/}	
P-1A, P-1B, P-1C	TCE	4	620	5
P-1E	TCE	4	600	5
P-6A	TCE	4	600	5

^{a/} Maximum sorbed concentrations of TCE are those concentrations in the vadose zone, under the conditions described, that will produce a concentration of TCE in groundwater at the water table that does not exceed the ACL concentration for TCE.

^{b/} Identified as a groundwater chemical of concern in the OU1 ROD (ESE, 1993a), and a chemical of concern in soil in the Base-Wide ROD for soils (ESE, 1996).

^{c/} µg/kg = micrograms per kilogram.

^{d/} ppbv = parts per billion, by volume.

^{e/} µg/L = micrograms per liter.

At such time as the results of soil-vapor monitoring indicate that the concentrations of TCE in soil vapor at a specific SVE monitoring point no longer exceed vapor-phase soil cleanup criteria, the vapor-extraction system in that area could be shut down, because the VOC mass remaining in that soil volume would be unlikely to represent a continued potential threat to groundwater. Soil-vapor monitoring should be continued for some period of time following system shut-down to evaluate whether the concentrations of TCE in soil vapor increase, as volatile constituents sorbed to soil or within the soil matrix diffuse into the soil pore spaces (the “rebound” effect). In some cases, VOC concentrations will continue to rebound above screening-level soil vapor criteria during equilibrium (shut-down) testing. In such cases, an approach similar to the SVE Termination or Optimization Process (STOP) protocol (Castle Air Force Base [AFB], 1999), currently being applied at several Air Force installations in California, should be

pursued to weigh the relative costs/benefits of continued operation of SVE systems having marginal extraction rates and high unit costs for VOC mass removal. Radian (2000b) has indicated that the STOP protocol will be applied at sites on DDJC-Sharpe that are undergoing SVE remediation.

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SECTION 4

REMEDIAL SYSTEMS EVALUATION

5 Ultimately, the effectiveness of a remediation system is judged by evaluating how well
6 it achieves its objectives; and the efficiency of the system is considered to be optimal if it
7 is effectively achieving its objectives at the lowest total cost, and/or in the shortest period
8 of time. The RAOs for the SVE and groundwater ETI systems were established in the
9 RODs (ESE, 1993a; *ibid.*, 1996). Because the effectiveness and efficiency of a
10 remediation system are directly related to its ability to achieve RAOs, the degree to
11 which these objectives are met can be used as a measure of system performance. This
12 RPO Phase II evaluation addresses the effectiveness and efficiency of the SVE systems
13 currently in operation at sites P-1A/P-1B/P-1C, P-1E, and P-6A; and examines the
14 effectiveness of the groundwater ETI systems and associated monitoring program.
15 Recommendations for optimizing remedial systems, enhancing the effectiveness of the
16 groundwater remedy and monitoring program, reducing OM&M costs, and renegotiating
17 site-specific cleanup goals for soil (i.e., performance criteria) based on these Phase II
18 evaluations, are presented in Section 5, together with suggestions for implementation of
19 the recommendations.

20 **4.1 RPO EVALUATION OF SOIL-VAPOR EXTRACTION SYSTEMS**

21 Soils at five of the VOC-contaminated sites identified at DDJC-Sharpe (Figure 4.1)
22 are currently undergoing remediation via SVE (Radian, 1999g; *ibid.*, 2000), to remove
23 VOCs (primarily TCE) from the vadose zone. The following subsections describe the
24 remedial design of the SVE systems and present an evaluation of the potential
25 effectiveness and efficiency of the systems.

26 The primary RAO of the SVE systems in operation at sites P-1A, P-1B, P-1C, P-1E,
27 and P-6A, is to reduce the concentrations of PCE and TCE in the vadose zone at these
28 locations. The cleanup goals reviewed in Section 3 are intended to represent levels that

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2 **Figure 4.1 Soil-Vapor Extraction Systems and Operations for the Period October**
3 **1998 – September 1999**

4

1 will prevent further degradation of groundwater quality that could result from continued
2 migration of TCE from vadose-zone soils to groundwater at dissolved concentrations
3 exceeding the ACL concentration for TCE. Protection of groundwater quality is
4 therefore the basis for requiring removal of CAH from vadose-zone soils at the five sites.

5 The soil-vapor cleanup level of 350 ppbv of TCE in soil vapor apparently was derived
6 on the basis of Henry's Law, which describes the concentration of a substance dissolved
7 in the aqueous phase at equilibrium with its vapor phase (Section 3.2; Appendices B and
8 C).

9 The Basewide ROD for DDJC-Sharpe (ESE, 1996) specifies that remediation
10 effectiveness will be evaluated during operation of the SVE systems by tracking the
11 cumulative mass of VOCs removed through time, and by conducting vadose-zone
12 modeling to assess the effects of VOCs remaining in the vadose zone on underlying
13 groundwater. The RAOs for vadose-zone cleanup will be considered to have been
14 achieved when the following conditions have been met:

- 15 • A plot of the cumulative VOC mass removed from a site approaches asymptotic
16 levels.
- 17 • The concentrations of TCE in soil vapor are equal to or less than the cleanup
18 standards. This condition apparently applies to every point in the vadose zone at
19 each site; and vapor-phase concentrations at each site are to be evaluated by
20 conducting "rebound" tests and collecting soil-vapor samples at a number of soil-
21 vapor monitoring points (VMPs).
- 22 • It can be demonstrated by the application of modeling that TCE remaining in the
23 vadose zone at each site will not migrate to the groundwater table at concentrations
24 that exceed ACL concentrations for TCE. In the absence of modeling, a vadose-
25 zone concentration of TCE at, or below 350 ppbv is considered to satisfy this
26 standard.
- 27 • The mass of TCE in the vadose zone has been removed to the extent technically
28 and economically feasible. If ACL concentrations have not been achieved in the

groundwater underlying an SVE site, consideration of technical and economic feasibility will include the following factors, at a minimum:

- a) Whether the technical limits of the SVE system have been reached, as demonstrated by asymptotic mass removal.
- b) Evaluation of the total cost and duration of continued groundwater ETI to meet ACL concentrations in groundwater at the site, in the absence of continued SVE operation.
- c) Evaluation of the incremental cost of continued operation of the SVE system at the site. "Incremental cost" will be estimated as the cost per pound of additional VOC mass removed from the site.
- d) Evaluation of the total cost and duration of continued operation of the SVE systems, including potential system enhancements, that would be necessary to achieve ACL concentrations in groundwater underlying the vadose zone at the site.
- e) Comparison, on a common basis (e.g., cost per pound of TCE removed) of the cost of continued SVE remediation with the cost of continued groundwater ETI.

The ROD requires the SVE systems at DDJC-Sharpe to be operated in cycles (i.e., periodically shut down for a period of time, and then re-started), in order to optimize CAH removal rates, or to evaluate the attainment of vadose-zone cleanup criteria.

4.1.1 Summary of Design Elements of SVE Systems

Current plans (Radian, 1999g; *ibid.*, 2000b) call for continued operation of vapor-extraction wells (VEWs) in areas where the concentrations of TCE in soil vapor exceed soil-vapor cleanup levels. Individual SVE wells were designed using information about the permeability of local soil to air, and estimated radii of influence (ROIs) obtained during SVE pilot testing in 1996 (Radian, 2000b). SVE wells have been installed at each site in an array that will allow a vacuum to be applied (at the VEWs) throughout the entire volume of affected soil. VMPs have been installed near the perimeter of each affected soil volume, within the radius of influence (ROI) of each VEW field, and near

hot spots (Radian, 2000b). Details of the proposed SVE and monitoring systems are summarized for each of the five sites below.

4.1.1.1 Sites P-1A, P-1B, and P-1C

Sites P-1A, P-1B, and P-1C are located within a large grassy field within the South Balloon (Figure 4.1). The area is generally level, although sections of the field are used for storage of soil excavated from other parts of the facility.

During Radian's 1996 cone penetrometer (CPT) investigation of sites P-1A/P-1B/P-1C, three irregular sub-areas were delineated within which the concentrations of TCE in soil-vapor samples exceed the cleanup criteria for TCE, specified in the ROD. The maximum detected concentration of TCE in soil vapor was 57,000 ppbv, with detected concentrations extending from a depth of about 4.5 feet bgs to a point just above the water table, at a depth of approximately 14 feet bgs. As a consequence of the spatial separation among the sub-areas, a separate SVE wellfield is required to remediate each of the three sub-areas. Each wellfield consists of several SVE wells, with wellheads connected by a manifold (a single "circuit") to a hookup in a location central to the SVE wells. The design of the hookup enables the wellfield to be operated using a single, trailer-mounted treatment unit (Section 4.1.1.4). The remediation system for site P-1A consists of 6 VMPs, 8 SVE wells on 2 extraction circuits (Table 4.1), and a design extraction-well flow rate of about 14 standard cubic feet per minute (scfm) (Table 4.2). The remediation system for site P-1B consists of 2 VMPs, 3 SVE wells on a single extraction circuit, and a design extraction-well flow rate ranging from 10.5 to 14 scfm. The remediation system for site P-1C consists of 8 VMPs, 5 SVE wells on a single extraction circuit, and a design extraction-well flow rate of about 10.5 scfm. The design total vapor-extraction rate for the four circuits at sites P-1A/P-1B/P-1C is about 200 scfm, with influent concentrations of VOCs in the vapor stream at system startup estimated to be about 8,000 ppbv (Radian, 1997a, Attachment 3). The total of direct and indirect capital costs for all SVE systems then planned for installation at DDJC-Sharpe was estimated (ESE, 1994a) to be approximately \$209,000 (in 1994 dollars). If the total of direct and indirect costs for all SVE systems are prorated among the operating SVE sites according to the number of VEWs installed at each site, then the total of direct and

TABLE 4.1
SVE SYSTEM DESIGN AND CONSTRUCTION DETAILS^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Circuit Number	Number of VMPs ^{b/}	Number of SVE Wells	Extraction Well Screened Interval (feet bgs) ^{c/}	Screen Length (feet) ^{d/}	Design Extraction Rate per Foot of Screen (scfm) ^{e/}	Total Design Extraction Rate per Circuit (scfm)
P-1A	1A1	6	4	5 – 15	10	1.4	56
	1A2		4	5 - 15	10	1.4	56
P-1B	1B1	2	3	5 – 12.5	7.5	1.4	35
P-1C	1C1	8	5	5 – 12.5	7.5	1.4	52.5
P-1E	1E1	2	2	5 – 17.5	12.5	2.2	55
P-6A	6A1	10	6	5 – 10	5	2.2	66
	6A2		6	5 - 10	5	2.2	66

^{a/} Design and construction details from Radian (2000b).

^{b/} VMP = vapor monitoring point.

^{c/} bgs = below ground surface.

^{d/} ft = feet.

^{e/} scfm = standard cubic feet per minute.

TABLE 4.2
SVE WELL DESIGN DETAILS^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Design Vapor-Extraction Rate (per well) (scfm) ^{b/}	Design Wellhead Vacuum		Design Radius of Influence (feet)
		(in. water) ^{c/}	(atm) ^{d/}	
P-1A	14	50	~ 0.12	50
P-1B	10.5 – 14	50	~ 0.12	50
P-1C	10.5	50	~ 0.12	50
P-1E	27.5	50	~ 0.12	70
P-6A	11	50	~ 0.12	45

^{a/} Design and construction details from Radian (2000b).

^{b/} scfm = standard cubic feet per minute.

^{c/} in. water = inches of water.

^{d/} atm = atmosphere; 407 in. water = 1 atm.

indirect capitals costs for the SVE systems at sites P-1A/P-1B/P-1C, prorated according to the 16 VEWs operating at the sites, is estimated to be about \$111,500 (in 1994 dollars) (Table 4.3).

Based on the 1996 soil-vapor data, Radian (1997a) estimated that approximately 9.3 pounds of TCE mass remained in the vadose zone in the vicinity of sites P-1A/P-1B/P-1C (Table 4.4). Considering the volume of soil at sites P-1A/P-1B/P-1C that is thought to be affected by TCE in the vadose zone, this is equivalent to an average concentration of 237 micrograms per kilogram ($\mu\text{g/kg}$) of TCE remaining in vadose-zone soils at sites P-1A/P-1B/P-1C.

4.1.1.2 Site P-1E

Site P-1E is located in the central part of the South Balloon (Figure 4.1). The area is generally level, and is paved with asphalt and concrete. During Radian's 1996 CPT investigation, an irregular area covering about 30,000 square feet, much of which is covered by pavement, and which extends beneath Building 649, was delineated within which the concentrations of TCE in soil-vapor samples exceeded the cleanup criteria for TCE, specified in the ROD. The maximum detected concentration of TCE in soil vapor was 1,400 ppbv, with detected concentrations extending from about 4.5 feet bgs to depths greater than 12 feet bgs. The water table is at a depth of about 19 feet bgs at site P-1E. The remediation system for site P-1E consists of 2 VMPs, 2 SVE wells on a single extraction circuit (Table 4.1), and a design extraction-well flow rate of about 27.5 scfm (Table 4.2). The design total vapor-extraction rate for the complete circuit is about 55 scfm, with influent concentrations of VOCs in the vapor stream at system startup estimated to be about 1,300 ppbv (Radian, 1997a, Attachment 3). The total of direct and indirect capitals costs for the SVE system at site P-1E, prorated according to the 2 VEWs operating at the site, is estimated to be about \$14,000 (in 1994 dollars) (Table 4.3).

Based on the 1996 soil-vapor data, Radian (1997a) estimated that approximately 0.5 pound of TCE mass remained in the vadose zone in the vicinity of site P-1E (Table 4.4). This is equivalent to an average concentration of 13 $\mu\text{g/kg}$ of TCE remaining in vadose-zone soils at the site.

TABLE 4.3
ESTIMATED TOTAL COSTS TO ACHIEVE CLEANUP GOALS^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Estimated Direct and Indirect Capital Costs ^{b/}	Estimated Annual OM&M Costs ^{c/}	Projected Range of Cleanup Times (days) ^{d/}	Projected Range of Costs for GAC ^{e/}	Estimated Range of Total Costs per Site	Estimated Range of Unit Costs per Site (\$/lb COC) ^{f/}
P-1A/P-1B/P-1C	\$111,500	\$8,000	50 - 400	\$900 - \$7,000	\$113,000 - \$127,000	\$12,200 - \$13,700
P-1E	\$14,000	\$8,000	50 - 4,400	\$900 - \$77,100	\$16,600 - \$188,000	\$32,000 - \$376,000
P-6A	\$83,500	\$8,000	50 - 4,400	\$900 - \$77,100	\$85,000 - \$257,000	\$21,400 - \$64,300

^{a/} Cleanup goals established for TCE in soil in terms of vapor-phase concentrations (Section 3.2).

^{b/} Direct and indirect capital costs for SVE systems estimated by ESE (1994a), in constant (1994) U.S. dollars, prorated among 3 systems.

^{c/} OM&M = operations, maintenance and monitoring (excluding granular activated carbon). Estimated annual OM&M cost for a single SVE system is \$24,000, prorated among three systems, in constant (1998) U.S. dollars.

^{d/} Range of cleanup times projected from pore-volume exchange rates presented by Radian (2000b).

^{e/} GAC = granular activated carbon, used to remove chemicals of concern (COCs) from SVE effluent vapor stream. Estimated cost for GAC is about \$2.00 per pound. GAC units assumed to require replacement on a quarterly basis.

^{f/} \$/lb COC = unit cost per pound of chemical of concern (TCE) removed from each site.

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TABLE 4.4
ESTIMATED MASS OF COCs IN VADOSE ZONE AND
PROJECTED TIMES TO ACHIEVE CLEANUP GOALS
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Volume of Soil Containing TCE ^{a/} (ft ³) ^{d/}	Mass of TCE ^{a/} (lbs) ^{e/}	Average Total Concentrations of TCE ^{b/} (µg/kg) ^{f/}	Projected Range of Cleanup Times ^{c/} (days)
P-1A/P-1B/P-1C	435,500	9.3	237	50 - 400
P-1E	412,100	0.5	13	50 - 4,400
P-6A	258,100	4.0	172	50 - 4,400

^{a/} Mass of TCE in vadose-zone soils and volumes of soil that contain TCE were estimated by Radian (1997a).

^{b/} Average concentration of TCE in an area is the mass of TCE in all phases (sorbed to soil, dissolved in soil water, and as a vapor) divided by the mass of the affected volume of soil, with the result converted to micrograms per kilogram. Unit weight of soil in each area from Radian (1997a).

^{c/} Time to achieve ROD cleanup goals projected from pore-volume exchange rates presented by Radian (2000b). Cleanup goals are established for TCE in soil in terms of vapor-phase concentrations (Section 3.2).

^{d/} ft³ = cubic feet.

^{e/} lbs = pounds.

^{f/} µg/kg = micrograms per kilogram.

1 **4.1.1.3 Site P-6A**

2 Site P-6A is located in a grass-covered field in the Central Area, near the western
3 boundary of the facility (Figure 4.1). During Radian's 1996 CPT investigation, an area
4 of about 100,000 square feet at Site P-6A was delineated within which the concentrations
5 of TCE in soil-vapor samples exceeded the cleanup criteria for TCE. The maximum
6 detected concentration of TCE in soil vapor was 35,000 ppbv, with detected
7 concentrations extending from about 4.5 feet bgs to a point just above the water table, at a
8 depth of about 16 feet bgs. The remediation system for site P-6A consists of 10 VMPs,
9 12 SVE wells on two extraction circuits (Table 4.1), and a design extraction-well flow
10 rate of about 11 scfm (Table 4.2). The design total vapor-extraction rate for the complete
11 2-circuit system is about 130 scfm, with influent concentrations of VOCs in the vapor
12 stream at system startup estimated to be about 4,600 ppbv (Radian, 1997a, Attachment
13 3). The total of direct and indirect capitals costs for the SVE system at site P-6A,
14 prorated according to the 12 VEWs operating at the site, is estimated to be about \$83,500
15 (in 1994 dollars) (Table 4.3).

16 Based on the 1996 soil-vapor data, Radian (1997a) estimated that approximately 4
17 pounds of TCE mass remained in the vadose zone in the affected area at site P-6A (Table
18 4.4). This is equivalent to an average concentration of 172 µg/kg of TCE remaining in
19 vadose-zone soils at the site.

20 **4.1.1.4 Vapor Treatment Unit and Operational Considerations**

21 At each site undergoing SVE treatment, the multiple SVE well circuits are connected
22 to a single manifold, so that any or all of the circuits at a particular site can be operated
23 using a single treatment unit (Radian, 1999g; *ibid.*, 2000b). The treatment unit is trailer-
24 mounted for mobility, and consists of a high-vacuum blower assembly, a moisture
25 separator, a heat exchanger, and two granular activated carbon (GAC) filtration units to
26 remove VOCs from the effluent vapor stream prior to discharge to the atmosphere. The
27 manifold valves were designed so that individual circuits can be cycled (periodically shut
28 down for a period of time and then re-started).

1 In operation, the trailer-mounted blower and treatment system is connected to the
2 manifold at a particular site and placed in active service for a period of time ranging from
3 30 to about 90 days (Radian, 1999g). At the end of that period, the blower and treatment
4 unit are shut down, disconnected from the manifold, and transported to another SVE site,
5 where the procedure is repeated. Operating an SVE system in cycles can provide several
6 benefits, including the option of incorporating small blower units and off-gas treatment
7 systems into the design; lower energy costs, because the system is not in continuous
8 operation; and capital cost savings, because a mobile unit, operated in cycles, can be used
9 to service multiple sites. In addition, vapor-phase concentrations in the subsurface may
10 increase during periods of system shut-down (the “rebound” effect). This can result in
11 higher VOC concentrations influent to the system during periods of operation, thereby
12 improving system efficiency (Sterrett, 1993).

13 **4.1.2 SVE System Performance**

14 Operational and cost factors considered during the evaluation of an operating SVE
15 remediation system typically include (Johnson *et al.*, 1990a and 1990b; USEPA, 1994b):

- 16 • Current and historic concentrations of contaminants in extracted vapor;
- 17 • Current and historic rates of removal of contaminant mass;
- 18 • Changes in contaminant concentrations and mass-removal rates through time;
- 19 and
- 20 • Total and incremental costs through time.

21 Several elements of the SVE system design were examined to assess whether the designs
22 address conditions at the five sites to a degree adequate to achieve RAOs for vadose-zone
23 soils. Design elements that were evaluated included source-area delineation and areas of
24 influence of the SVE systems; effectiveness of emission controls; and projected cleanup
25 times and cumulative costs. Historic system performance, through the period of
26 operation ending in the third quarter 1999, was also reviewed.

27 **4.1.2.1 Source-Area Delineation and Areas of Influence of SVE Systems**

28 The site-specific ROI of individual VEWs is an important parameter in the design of
29 an SVE system (Johnson *et al.*, 1990b; Sterrett, 1992). The *design ROI* is the maximum

1 radial distance from a VEW, operating at its design vacuum and flow rate, at which a
2 measurable pressure difference occurs, as a result of the well operation. Vapor and
3 vapor-phase COCs in the subsurface within the ROI of the well are induced to move
4 toward the operating well as a consequence of the pressure gradients existing within the
5 volume encompassed by the radius of influence (the *zone of influence*).

6 In a typical SVE well field, extraction wells are installed within, and surrounding, the
7 volume of soil contaminated with VOCs, and are located so that the volumes
8 encompassed by the ROIs of individual wells overlap to some extent (Sterrett, 1993), and
9 so that the entire volume of contaminated soil is contained within the zone of influence of
10 the entire well field. In this situation, when the system is in operation, soil vapor at every
11 point within the volume of contaminated soil will move toward a well under the influence
12 of the pressure gradients induced by the extraction wells. As vapor moves through the
13 volume of contaminated soil toward SVE wells, it is replaced by cleaner air moving at
14 slow rates from surrounding, uncontaminated soil, and by air moving downward into the
15 vadose zone from the atmosphere (Johnson, 1990b; USEPA, 1994b). An SVE well field
16 is appropriately designed if measurable pressure gradients can be established throughout
17 the entire volume of contaminated soil when the SVE system is in operation; and is
18 optimized when this is achieved with the fewest number of wells, operating at the lowest
19 total extraction rate.

20 Because of the limitations on remediation imposed by the ROI of SVE wells, adequate
21 delineation of VOC sources and characterization of the extent of VOCs in the subsurface
22 is a necessary precursor to the design of a successful SVE system. The extent of VOC
23 contaminants in the vadose zone at sites P-1A, P-1B, P-1C, P-1E, and P-6A, has been
24 evaluated during the course of several investigations (ESE, 1990; *ibid.*, 1994a; Radian,
25 1997a) by collection of soil samples from soil borings and CPT points and using soil-
26 vapor sampling techniques (Section 2.3.1.2). The extent of TCE, as defined by the 350-
27 ppv TCE isoconcentration contour, appear to have been adequately characterized in soil
28 vapor at sites P-1A/P-1B/P-1C, and P-6A (Radian, 2000b).

29 Characterization of the extent of TCE in the subsurface at site P-1E (Radian, 2000b) is
30 less certain (in particular, in the northern part of the site), because of the spatial

1 separation of the CPT soil-vapor sampling points (ranging from about 50 feet to more
2 than 100 feet). The spatial separation of soil-vapor sampling points at site P-1E is
3 approximately the same as the design ROI of VEWs at the site (Table 4.2). If the extent
4 of TCE in soil at site P-1E has not been sufficiently characterized, it is possible that some
5 volume of soil, containing TCE at levels that exceed RAO concentrations, could remain
6 unaffected by SVE remediation. However, Parsons recognizes that the access limitation
7 imposed by buildings in the area necessarily restrict the amount of additional
8 characterization that could be completed.

9 The design well-field configurations were examined for each of the sites currently
10 undergoing remediation using SVE. Assuming that the extent of soil contamination has
11 been adequately characterized at each site (as presented by Radian [1997a and 2000b]),
12 and that the design ROIs (Table 4.2) can be achieved, the well fields proposed appear to
13 be adequate to induce vapor movement through the entire volumes of contaminated soil
14 at each of the sites, on the basis of the criteria described above. The adequacy of site
15 characterization, and the operational characteristics of the well fields, and of individual
16 VEWs, should continue to be assessed by periodic monitoring during system operation.

17 **4.1.2.2 Effectiveness of Emission Controls**

18 Vapor-phase emissions of VOCs from the SVE systems at DDJC-Sharpe apparently
19 cannot exceed a total mass of 2 lbs/day, in accordance with the requirements of
20 SJVUAPCD Rule 2201, the ROD-specified ARAR dealing with allowable air emissions
21 from the systems (Section 3.1.3). The requirements of Rule 4651, which regulates VOC
22 emissions from soil decontamination activities, may not be applicable to SVE system
23 operation at DDJC-Sharpe because sites affected by accidental spillage of less than 42
24 gallons of liquids containing VOCs are exempt under the rule. A total mass of about 13.8
25 pounds of TCE is estimated to remain in vadose-zone soils at the three DDJC-Sharpe
26 SVE areas (Table 4.4). Using the density of TCE (1.464 grams per cubic centimeter
27 [g/cm³]; Table C.1, Appendix C), the total volume TCE in the vadose zone at the three
28 SVE sites is estimated to be about 1.1 gallon. Accordingly, the requirements of Rule
29 4651 do not appear to apply to SVE remediation activities at DDJC-Sharpe.

1 The maximum rate of vapor-phase VOC mass removal projected to occur at any of the
2 SVE sites is about 0.4 pounds per day (lbs/day) (Section 3.1.3), which may be realized
3 during initial system startup and prove-out for the systems at sites P-1A/P-1B/P-1C. The
4 GAC treatment system is projected in design documents (Radian, 1997a, Attachment 3)
5 to be capable of removing 50 percent of influent VOC mass from the vapor stream, prior
6 to discharge to the atmosphere. During system operation, elevated humidity in the
7 extracted soil vapor may reduce the projected removal efficiencies, because water vapor
8 will interfere with the sorptive capacity of the carbon (USEPA, 1994b). Nevertheless, in
9 the worst case (sites P-1A/P-1B/P-1C), probably less than 1 lb/day of VOC mass will be
10 discharged to the atmosphere. Discharges to the atmosphere from all other locations will
11 probably not exceed 0.2 lb/day of vapor-phase VOC mass. Therefore, treatment of the
12 effluent vapor stream using GAC filters should result in acceptable levels of VOC
13 emissions from the SVE systems.

14 In fact, direct discharge of untreated vapor-phase effluent from all four circuits at sites
15 P-1A/P-1B/P-1C operating simultaneously probably would not introduce more than 1
16 lb/day of VOC mass to the atmosphere (Radian, 1997a, Attachment 3). Because the SVE
17 blower and treatment system has been designed to operate at only a single site at any
18 given time, this represents the maximum amount of VOC mass that could be introduced
19 to the atmosphere during SVE operations at DDJC-Sharpe. Therefore, GAC treatment of
20 extracted soil vapor may not be necessary.

21 In fact, the SVE mass-removal rates reported for the prove-out period of the SVE
22 systems at DDJC-Sharpe can be used to evaluate whether GAC treatment of extracted
23 vapor is necessary. During the initial 10-day period of system prove-out, when mass-
24 removal rates are typically greatest, Circuits 1A1 and 1A2 at site P-1A each removed
25 about 2 pounds of TCE mass; Circuit B1 (site P-1B) removed about 0.7 pounds of TCE
26 mass; and Circuit C1 (site P-1C) removed about 4 pounds of TCE mass (Radian, 2000b).
27 Thus, a total of about 9 pounds of TCE mass was removed from the vadose zone at sites
28 P-1A/P-1B/P-1C during the first 10 days of the prove-out period. TCE is expected
29 (Radian, 1997a, Attachment 3) to comprise approximately 75 percent of the total VOC
30 mass in the untreated vapor effluent stream at sites P-1A/P-1B/P-1C. Therefore, a mass
31 of approximately 12 pounds of total VOCs was probably removed from the vadose zone

1 during the 10-day period. If the effluent vapor stream had been discharged without
2 treatment, an average of about 1.2 lbs/day of total VOC mass would have been
3 introduced to the atmosphere. Daily discharge of less than 2 pounds of VOC mass would
4 not violate the terms of SJVUAPCD Rule 2201, or the conditions of the ROD (ESE,
5 1996).

6 As a GAC treatment system is used, the VOC removal efficiency of the activated
7 carbon gradually decreases, as volatile chemicals sorb to the carbon (USEPA, 1994b).
8 After some period of operation, the GAC must be replaced or regenerated to restore its
9 ability to remove VOCs from the vapor stream. The trailer-mounted SVE blower and
10 treatment system incorporates twin GAC canisters, each containing 400 pounds of
11 activated carbon (Radian, 2000b). For the purposes of developing the conceptual design
12 for the SVE systems, ESE (1994a) assumed that the GAC canisters would require
13 change-out (replacement or regeneration) on a quarterly basis (every 3 months).

14 **4.1.2.3 Projected Cleanup Times and Cumulative Costs**

15 In conjunction with system design and prove-out, Radian (2000b) calculated a travel
16 time for movement of vapor through a distance equal to the radius of influence of an
17 individual SVE well to estimate a pore-volume exchange rate at each site, and then
18 assumed that movement of between 50 and 200 pore volumes of air through the affected
19 areas would be required to achieve soil-vapor RAOs. On the basis of these calculations,
20 Radian (2000b) estimated that one pore-volume exchange occurred at sites P-1A/P-1B/P-
21 1C every one to 2 days; and that one pore-volume exchange occurred at sites P-1e and P-
22 6A every one to 22 days. If it is necessary to move between 50 and 200 pore volumes of
23 air through the affected areas to achieve soil-vapor RAOs, then a period of time ranging
24 from 50 days to 400 days will be required to achieve RAOs for soil vapor at sites P-1A/P-
25 1B/P-1C, and a period of time ranging from 50 to 4,400 days will be required to achieve
26 RAOs for soil vapor at sites P-1E and P-6A (Table 4.4). If these projections are accurate,
27 and if GAC treatment of extracted vapor is necessary, the GAC canisters used in the SVE
28 vapor-treatment system will require replacement/regeneration from at least once (sites P-
29 1A/P-1B/P-1C) to possibly 50 times (sites P-1E and P-6A). Commercial GAC currently
30 costs approximately \$2 per pound (or about \$800 for each 400-pound canister). This

1 suggests that GAC treatment costs may become a significant part of long-term operations
2 costs, if the SVE systems remain operational for long periods of time (Table 4.3).

3 Based on experience in designing, installing, and operating numerous SVE systems,
4 Parsons estimates that annual OM&M costs (excluding GAC) for the three general SVE
5 areas would be approximately \$24,000. This is equivalent to annual OM&M costs of
6 about \$8,000 per area, assuming that the SVE treatment system is operated at each site
7 for a period of 4 months (one-third of a year), and that the total costs are evenly prorated
8 among the three areas. The total cost required to achieve RAOs for soil at each site is the
9 sum of the direct and indirect capital costs of system installation at the site, together with
10 the OM&M and GAC costs through the period required for system operation. If the
11 projected lengths of the time periods required to achieve RAOs are correct, then the total
12 costs of SVE remediation are estimated to range from about \$17,000 (site P-1E) to more
13 than \$250,000 (site P-6A) (Table 4.3). These correspond to projected costs per pound of
14 TCE removed from the vadose zone ranging from about \$12,200 (sites P-1A/P-1B/P-1C)
15 to more than \$370,000 (site P-1E). The excessive unit cost that might result for SVE
16 remediation at site P-1E is a consequence of the long period that might be required for
17 OM&M (4,400 days) and the low COC mass (about 0.5 pound of TCE in soil at the site).

18 The technique of using calculated vapor travel times and pore-volume exchange rates
19 to estimate the length of time required to achieve RAOs at each site apparently relied on
20 an assumption that soil in the vadose zone approximately comprises a homogeneous
21 porous medium (Radian, 2000b). Actual SVE sites are not so ideal, and in field
22 situations, a contaminant may become trapped within fine-grained, low-permeability
23 materials that are surrounded by sandy soils of higher permeability. In this situation,
24 induced vapor flow moves around the lower-permeability contaminated zone, and the
25 venting mass-removal rate becomes limited by the rate of vapor-phase chemical diffusion
26 from the low-permeability zone into the moving vapor stream (Johnson *et al.*, 1990a).
27 Mass removal from heterogeneous materials of varying permeability is therefore nearly
28 always slower than the rate of mass removal from homogeneous, permeable materials,
29 and is expressed in terms of venting efficiency (the ratio of the rate of mass removal from
30 a heterogeneous system to the rate of mass removal from a homogeneous system).

1 Soils in the subsurface at DDJC-Sharpe are heterogeneous, and consist of relatively
2 permeable zones of sandy (occasionally gravelly) layers, interbedded with lower
3 permeability silt and clay strata (Section 2.2.3). Therefore, rates of venting mass removal
4 probably will rapidly become limited by the rate of chemical diffusion, and it is unlikely
5 that RAOs for soil will be achieved within the time periods predicted (Table 4.4). In fact,
6 Radian (2000b) has noted that VOC mass removal at DDJC-Sharpe appeared to become
7 diffusion-limited at some point during the prove-out periods. Parsons used analytical
8 methods developed by Johnson *et al.* (1990a), together with the chemical properties of
9 TCE, and site-specific soil properties, to estimate the venting efficiencies that might be
10 achieved at each of the SVE sites. Estimated venting efficiencies for TCE ranged from
11 about 7 percent (at site P-1E) to about 10 percent (at site P-6A). This suggests that the
12 periods of time required to achieve RAOs for soil at DDJC-Sharpe could be anywhere
13 from 10 to 14 times longer than have been estimated using the assumption that soil at
14 DDJC-Sharpe is a homogeneous porous medium (Radian, 2000b). The OM&M, GAC
15 costs, and total costs for SVE remediation also would be correspondingly greater.

16 **4.1.2.4 Actual Performance of SVE Systems**

17 During 1999 and 2000, the SVE systems installed at DDJC-Sharpe were operated at
18 all circuits and all sites. Each circuit was actively operated in two phases, except the
19 circuit at site P-1C, which was active during only a single operations phase (Radian,
20 2000b).

21 The results of performance monitoring of the SVE systems during operation (details in
22 Radian, 2000b) indicate that the systems at all sites are removing VOCs from the vadose
23 zone. Operation of the SVE system was continued at each site until VOC concentrations
24 in vapor-phase influent had declined to detection limits, or until the mass-removal rate
25 had become asymptotic. For the period October 1998 through July 2000, a total of 27.6
26 pounds of TCE was removed by SVE operations at DDJC-Sharpe (Table 4.5).

27

TABLE 4.5
ACTUAL SVE MASS REMOVAL, 1999 - 2000^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Site	Circuit Number	TCE Mass Originally Estimated to be Present (lbs) ^{b/}	Period of Operation (days) ^{c/}	Cumulative TCE Mass Removed During Period ^{d/} (lbs)	Rate of TCE Mass Removal During Period (lbs/day) ^{e/}	Cost of TCE Mass Removal During Period (\$/lb) ^{f/}
P-1A	1A1	9.3 ^{g/}	160	8.0	0.05	\$4,700
	1A2		212	8.2	0.04	
P-1B	1B1		160	1.5	0.01	
P-1C	1C1		95	9.2	0.1	
P-1E	1E1	0.5	40	0.16	0.004	\$103,800
P-6A	6A1	4.0	33	0.3	0.009	\$188,200
	6A2		47	0.16	0.003	

^{a/} Prove-out and operational details from Radian (2000b).

^{b/} lbs = pounds.

^{c/} Total number of days operated during one or two operational periods..

^{d/} Cumulative TCE mass removal is total amount of mass removed during entire period of operation.

^{e/} lbs/day = pounds per day.

^{f/} \$/lb = unit cost of TCE mass removal (U.S. dollars per pound of TCE removed during period of operation), incorporating direct and indirect capital costs, and OM&M cost of \$65 per day of operation.

^{g/} Total mass of TCE originally estimated to be present in subsurface in vicinity of sites P-1A, P-1B, and P-1C.

3 The rate of removal of TCE mass from the vadose zone at sites P-1A/P-1B/P-1C
4 during the operational period exceeded the rate projected during system design (Table
5 4.5). Active SVE treatment was conducted at sites P-1A/P-1B during the initial and
6 second phase of operations; the system at site P-1C was not brought online until the
7 second phase of operations. Concentrations of TCE in the vapor stream influent to the
8 SVE system during the initial phase of operations at sites P-1A/P-1B were in excess of
9 1,000 ppbv (Radian, 2000b). After an operational period ranging from about 50 to 100
10 days, influent concentrations of TCE had decreased to levels below the current vapor
11 cleanup standard of 350 ppbv, or were asymptotically approaching the vapor cleanup
12 standard. The SVE treatment system then was shut down, and contaminants in the
13 subsurface were allowed to re-equilibrate with soil vapor for a period of time
14 (“rebound”). The treatment system then was placed in service for a second phase of

1 operations, and was actively operated at all circuits at sites P-1A/P-1B/P-1C for periods
2 ranging from about 60 to 125 days. During the inactive (“rebound”) period between
3 operations, the vapor-phase concentrations in the subsurface had increased, so that the
4 concentrations of TCE in the vapor stream influent to the SVE system during the second
5 phase of operations at sites P-1A/P-1B/P-1C again exceeded 1,000 ppbv (Radian, 2000b).
6 Influent concentrations of TCE rapidly decreased to levels below the vapor cleanup
7 standard, or were asymptotically approaching the vapor cleanup standard during the
8 second phase of system operation, when the SVE treatment system at sites P-1A/P-1B/P-
9 1C again was shut down.

10 Cumulative removal of TCE mass by all operational circuits at sites P-1A/P-1B/P-1C
11 increased progressively through the duration of the operational periods (Figures 4.2, 4.3,
12 4.4, and 4.5), although the rate of mass removal decreased near the end of the period of
13 operations at each circuit (indicated by the progressive flattening of the slope of each
14 curve in the referenced Figures). However, despite the decrease in the rate of mass
15 removal at sites P-1A/P-1B/P-1C, mass-removal rates at these sites do not appear to have
16 become asymptotic, suggesting that additional TCE mass could be removed from the
17 vadose zone at these sites with continued SVE system operation. As of July 2000, SVE
18 operations at sites P-1A/P-1B/P-1C had removed an estimated 26.9 pounds of TCE from
19 the subsurface (Table 4.5).

20 Much less TCE mass was removed from the vadose zone during the relatively shorter
21 periods of operation at sites P-1E and P-6A (Table 4.5); and the rates of removal of TCE
22 mass from the vadose zone at sites P-1E and P-6A were less than the rates projected
23 during system design. Active SVE treatment was conducted at sites P-1E and P-6A
24 through two phases of operations. Concentrations of TCE in the vapor stream influent to
25 the SVE system during the initial phase of operations at site P-1E and circuit 6A2 of site
26 P-6A were below the vapor cleanup standard (Radian, 2000b). After an operational
27 period ranging from about 14 to 28 days, influent concentrations of TCE had decreased to
28 levels well below the vapor cleanup standard, or to levels below detection limits. The
29 SVE treatment system then was shut down, and a “rebound” period ensued. During the
30 inactive (“rebound”) period between operations, the vapor-phase concentrations of TCE

1

2 **Figure 4.2 Cumulative Mass Removal for Site P-1A, Circuit 1A1**

3

1 **Figure 4.3 Cumulative Mass Removal for Site P-1A, Circuit 1A2**

2

1 **Figure 4.4 Cumulative Mass Removal for Site P-1B, Circuit B1**

2

1 **Figure 4.5 Cumulative Mass Removal for Site P-1C, Circuit C1**

2

1 in the subsurface at site P-6A, circuit 6A2 appear to have recovered to near their former
2 levels. However, after startup of the second phase of operations, concentrations of TCE
3 in the vapor stream influent to the SVE system at site P-1E and site P-6A, circuit 6A1,
4 remained below detection limits (Radian, 2000b). The treatment system continued in
5 active operation at sites P-1E and P-6A for periods ranging from about 16 to 28 days for
6 the second operational phase.

7 Cumulative removal of TCE mass by all operational circuits at sites P-1E and P-6A
8 increased progressively, though slowly, through the duration of the operational periods
9 (Figures 4.6, 4.7, and 4.8), and appears to have become asymptotic prior to, or during the
10 second phase of operations at each site (indicated by the nearly flat slope of each curve in
11 the Figures during later time). The asymptotic nature of the mass-removal curves for
12 sites P-1E and P-6A suggests that little additional TCE mass could be removed from the
13 vadose zone at these sites with continued operation of the SVE system. As of July 2000,
14 SVE operations at sites P-1E and P-6A had removed approximately one-half pound of
15 TCE from the subsurface (Table 4.5).

16 The unit cost per pound of TCE removed by the SVE systems also can be estimated,
17 using the cumulative TCE mass removed by each system, and the periods of operation.
18 Assuming that the annual OM&M costs of SVE system operation are approximately
19 \$24,000, then the cost per day of SVE operation is about \$65. The unit cost per pound of
20 TCE removed is the sum of the direct and indirect capital costs for system installation,
21 together with the OM&M costs through the period of operation. For example, the total
22 direct and indirect capital costs for installing the SVE system at sites P-1A/P-1B/P-1C is
23 estimated to be about \$111,500 (Section 4.1.1.1). Although the SVE system was only
24 operational for a period of 160 days at site P-1A (circuit 1A1), 160 days at site P-1B, and
25 95 days at site P-1C, the system was operational at site P-1A (circuit 1A2) for a period of
26 212 days. Therefore, the SVE system was operational at sites P-1A/P-1B/P-1C for a 212-
27 day period, and total OM&M costs of \$13,780 (212 days at a daily cost of \$65) are
28 assigned to these sites. Therefore, to date, 26.9 pounds of TCE have been removed from
29 the vadose zone at sites P-1A/P-1B/P-1C, at a total estimated cost of about \$125,280.
30 This is equivalent to a unit cost of approximately \$4,700 per pound of TCE removed

1

2 **Figure 4.6 Cumulative Mass Removal for Site P-1E, Circuit E1**

3

1 **Figure 4.7 Cumulative Mass Removal for Site P-6A, Circuit 6A1**

2

1 **Figure 4.8 Cumulative Mass Removal for Site P-6A, Circuit 6A2**

2

(Table 4.5, Column 7). This is approximately one-third the unit cost per pound of TCE removed, estimated on the basis of projected cleanup times (Table 4.3). The lower unit cost to date has occurred because the systems at sites P-1A/P-1B/P-1C have removed approximately 3 times the TCE mass originally estimated to be in the vadose zone in this area. As a consequence of the low mass of TCE removed from the vadose zone at sites P-1E and P-6A, the estimated unit costs per pound of TCE removed from the vadose zone at these sites are considerably greater – about \$104,000 per pound and \$188,000 per pound, respectively (Table 4.5).

4.1.3 Potential System Enhancements and Associated Cost Savings

As is apparent from the preceding discussion, some degree of uncertainty is associated with aspects of the design and operation of SVE systems to remediate soil at DDJC-Sharpe. In particular, the degree to which COC mass removal may be limited by vapor-phase chemical diffusion will not be known until the SVE systems have been in operation for some time. Accordingly, current projections regarding the length of time required to achieve RAOs for volatile COCs in soil must be regarded as speculative.

Nevertheless, the RPO evaluation of the SVE systems at DDJC-Sharpe has identified several elements of system design and operation that may enable the systems to be operated more effectively, more cost-effectively, or more efficiently. Design and operational elements that could be altered to enhance the effectiveness of the SVE systems are associated with delineation of extent of source-areas; emission controls; and implementation of passive soil venting to supplement active SVE treatment. Additional efficiencies could be realized if the recommended system enhancements were to be implemented in conjunction with regulatory changes to the RAOs for TCE in soil vapor, described in Section 3.2. Although not all the beneficial effects of SVE system enhancement can be quantified, their implementation should result in reduced OM&M costs, a decrease in the time required to achieve RAOs for TCE in soil, or both. Any reduction in the operational life of the SVE systems, in turn, is likely to generate cost savings.

1 **4.3.1.1 Source Area Delineation**

2 Adoption of alternative, site-specific RAOs for concentrations of TCE in the ranges of
3 600 to 620 ppbv in soil vapor (Section 3.2) would reduce the volumes of soil requiring
4 SVE remediation at each of the three general SVE areas. In conjunction with additional
5 characterization of TCE source areas, this could enable estimates of the volumes of soil
6 containing TCE at concentrations representing a potential threat to groundwater to be
7 decreased. Those areas having relatively greater concentrations of TCE in soil could then
8 be targeted for SVE remediation, which probably could be accomplished using systems
9 smaller than those currently in operation.

10 **4.3.1.2 Emission Controls**

11 The results of influent vapor-stream sampling during SVE system prove-out (Radian,
12 2000b), indicate that direct discharge of untreated vapor-phase effluent from SVE
13 operations at DDJC-Sharpe probably would not introduce more than about 1 lb/day of
14 total VOC mass (the daily maximum VOC mass discharge allowed under SJVUAPCD
15 rules [152 lbs/day]) to the atmosphere. If SVE monitoring data continue to indicate that
16 the VOC mass in the treatment-system influent vapor streams is less than the allowed 2
17 lbs/day at each site, direct discharge of untreated vapor-phase effluent from SVE
18 operations at DDJC-Sharpe would be acceptable under the APCD regulations, and the
19 GAC treatment system could be removed from the SVE blower unit. This possibility
20 should be evaluated during operational periods for the SVE systems by collecting and
21 analyzing samples of the extracted vapors at each SVE site from the influent lines to the
22 treatment system.

23 Once VOC vapor concentrations fall within regulatory emissions requirements,
24 elimination of GAC treatment of the SVE vapor effluent stream would generate
25 substantial cost savings over the operational life of the SVE systems. Assuming that the
26 systems will operate at the three sites through the longer operational periods projected
27 above (400 days at sites P-1A/P-1B/P-1C; 4,400 days at site P-1E; and 4,400 days at site
28 P-6A), elimination of GAC treatment could result in total cost savings of more than
29 \$160,000 (Table 4.3, Column 5).

4.1.3.3 Passive Soil Venting

SVE systems at DDJC-Sharpe are operated in cycles, so that the trailer-mounted SVE blower and treatment system are active at only one of the three SVE areas at any given time. This method of operation presents an opportunity to implement passive SVE treatment technology at the two inactive SVE sites, concurrently with active SVE treatment proceeding at the other site.

Theory of Passive Venting Treatment Process

All venting systems rely on the preferential partitioning (as indicated by the Henry's Law constant; Lyman *et al.*, 1990) of VOCs to the vapor phase from the dissolved or solid phases (in soil water or adsorbed to soil particles). Active venting systems require that air be moved through soil, *in situ* or *ex situ*, by means of fans or blowers, connected to wells or vent lines (Brown *et al.*, 1991; Gross *et al.*, 1992; Johnson *et al.*, 1990a and 1990b). Passive systems, in contrast, utilize pressure differences between interstitial air/vapor in soil pore spaces, and the atmosphere, to induce a flow of air and vapor from soil into the vent wells or lines, which discharge to the atmosphere. Because removal of vapor-phase chemicals from soil pore spaces increases the chemical concentration gradient between the sorbed and vapor-phase chemicals, this will promote the further partitioning of chemicals from the adsorbed phase to the vapor phase, with subsequent removal via the venting process (Gross *et al.*, 1992).

Alternatively, if atmospheric pressure exceeds the interstitial vapor/air pressure in the soil pore spaces, fresh air will move from the atmosphere into the soil, diluting chemicals in the vapor phase and causing additional partitioning of chemicals from the sorbed to the vapor phase (again as a consequence of the increased chemical concentration gradients), for subsequent flushing from the system (Rossabi *et al.*, 1993; Weeks, 1994). In addition, if the volume of contaminated soil is covered by an impermeable membrane (e.g., asphalt pavement), the removal efficiency of the venting system should be enhanced (Peters *et al.*, 1994).

Conceptual Implementation of Passive Soil Venting at DDJC-Sharpe

Successful volatilization of chemicals from soil depends primarily on the properties of the chemicals to be removed, and to a lesser extent on the grain size, mineralogy, air permeability, and moisture content of the soil (Lyman *et al.*, 1990; Johnson *et al.*, 1990). The COCs in soil at DDJC-Sharpe (primarily TCE) have relatively low boiling points (190 degrees Fahrenheit [°F] for TCE) (Montgomery and Welkom, 1990) and relatively high Henry's Law constants (0.009 atmosphere – cubic meters per mole [atm-m³/mol] for TCE; Appendix C, Table C.1), indicating that active or passive venting techniques can be successful in removing these chemicals from the vadose zone. In fact, passive venting techniques have been used successfully to remove TCE from soils similar in character to the soils at DDJC-Sharpe (Sulborski *et al.*, in press).

Analytical methods developed by Johnson *et al.* (1990a) were used to estimate the vapor-flow rates and resulting mass-removal rates if the SVE systems at DDJC-Sharpe were to be used for passive venting during inactive periods. Using the properties of TCE, and the properties of the soils at the three sites, Parsons calculated that if a differential pressure of only 0.005 atm were established between the atmosphere and interstitial air in soil within the vadose zone, a flow rate of approximately 1.5 scfm per well, or greater, would be produced (compare with design flow rates of active SVE wells ranging from about 10 to 28 scfm; Table 4.2). This corresponds to a vapor-flow velocity of approximately 0.003 feet per minute at a radius of 10 feet from the well, as compared with vapor-flow velocities of about 0.03 feet per minute estimated for the current well designs.

Under optimum conditions, the VOC mass-removal rate is approximately proportional to the vapor-flow velocity induced by the well (Johnson *et al.*, 1990a). Thus, the mass-removal rate of a continuously-operating passive SVE system would be approximately one-tenth the mass removal rate of a continuously-operating active SVE system. However, if the active SVE systems, as designed, were to be modified to allow passive venting to occur during inactive periods, mass removal would continue even though the system was not in active operation, and the length of time required to achieve RAOs in soil at the three general areas could be reduced, perhaps by as much as 10 percent.

1 Assuming that the systems would be in active operation at the three sites through the
2 longer operational periods projected above (400 days at sites P-1A/P-1B/P-1C; 4,400
3 days at site P-1E; and 4,400 days at site P-6A), a 10 percent reduction in operational time
4 that might occur as a consequence of implementing passive venting could result in a 10-
5 percent cost savings for OM&M (about \$20,000; Table 4.3, Columns 3 and 4). If GAC
6 treatment of the vapor stream effluent from active SVE systems is not eliminated, a 10-
7 percent reduction in operational time for the active SVE systems would also generate
8 substantial savings in GAC costs (about \$16,000).

9 Only minor modifications would be required to adapt the SVE systems for periodic
10 use as passive venting systems. During periods of inactivity at an SVE site, a valve or
11 vent in the manifold, or at individual wellheads, could be left open to the atmosphere,
12 thereby allowing free exchange of air and vapor between the atmosphere and the SVE
13 well system. A modification of this type could be implemented at little or no additional
14 cost. Treatment of the passively-extracted effluent vapor stream would not be necessary,
15 because VOC mass discharge from a passive venting system to the atmosphere would be
16 much less than mass discharge from an active SVE system, and would be considerably
17 less than the 2-pound daily maximum total VOC mass allowed by APCD regulations
18 (Section 4.1.2.2).

19 Because it is not possible to calculate the rate of additional mass removal that would
20 results from implementation of a passive-venting remediation strategy, the potential cost
21 savings associated with passive venting cannot be quantified absolutely. However, any
22 enhancement to the SVE remediation systems that reduces the length of time required to
23 achieve RAOs will have associated cost savings.

24 **4.2 EVALUATION OF GROUNDWATER REMEDIAL SYSTEMS**

25 In this section the full-scale groundwater ETI systems operating at DDJC-Sharpe are
26 described, and the performance of the extraction wells, treatment systems, and water-
27 management system is evaluated. The effectiveness of the system to date is reviewed,
28 opportunities for optimization are developed, and potential cost savings are reviewed.

4.2.1 Description of Current Groundwater Remediation Systems

Three separate groundwater extraction and treatment systems, designed to remove VOCs from contaminated groundwater, currently are in operation at DDJC-Sharpe. These systems, shown on Figure 4.9, are referred to as the North Balloon, Central Area, and South Balloon Groundwater Treatment Plants. The process relationships among the three GWTPs are presented in Figure 4.10; and a piping schematic for the three systems showing extraction well locations, contaminated and treated water piping, and current discharge options (storm drains discharging to surface water, percolation ponds, injection wells, and offsite re-use) is shown on Figure 4.11.

4.2.1.1 North Balloon GWTP System

The groundwater ETI system in the North Balloon area consists of 18 extraction wells (17 of which currently are in operation) and facilities to treat and manage extracted groundwater. Design discharge rates for the extraction wells range from 8 to 40 gallons per minute (gpm) (Table 4.6); current actual production rates range from 0 (well EWNA7 was removed from service in the 4th quarter of 1997) to about 41 gpm. Most of the wells completed in monitoring zones A and B are not capable of producing groundwater at their design extraction rates; however, wells completed in monitoring zone “C” produce at rates that meet or exceed design capacities (Radian, 1999a; *ibid.*, 1999g). The total discharge rate for the entire North Balloon extraction system is variable through time, depending upon the number of wells that may be in service, and their production rates. For example, the average total discharge rates for 1998 and 1999 were 333 gpm and 278 gpm, respectively (Radian, 1999a; *ibid.*, 1999g).

Groundwater extracted from the North Balloon area is directed to the North Balloon GWTP (Figure 4.10). The North Balloon GWTP consists of twin, counter-flow stripping towers in series; a chemical sequestration system; a control building and ancillary equipment; and a discharge pipeline to the adjacent Dynege® plant. The treatment system was originally designed for a capacity of 500 gpm, but currently operates at rates ranging from about 300 to 350 gpm, or less (Radian, 1999g).

1

2 **Figure 4.9 Extraction Well Locations**

3

1 **Figure 4.10 Flow Schematic for DDJC-Sharpe Groundwater Treatment Plants**

2

1 **Figure 4.11 Groundwater Treatment Systems Piping Schematic**

2

TABLE 4.6
RECENT PRODUCTION HISTORY^{a/}
OF
GROUNDWATER EXTRACTION WELLS
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Well	Monitoring Zone of Completion Interval	Approximate Screened Interval (ft bgs) ^{b/}	Design Production Rate (gpm) ^{c/}	Actual Production Discharge Rate (1999) (gpm)	TCE Concentration in Well Discharge (mg/L) ^{d/} (Date) ^{e/}		Current TCE Removal Rate (lbs/year) ^{f/}
Extraction Wells in North Balloon Area							
EWNA1	A	30-40	10	3.3	14	07/14/00	0.20
EWNA2	A	55-65	30	11.9	22	07/14/00	1.15
EWNA3	A	40-50	20	23.6	8.9	07/17/00	0.92
EWNA4	A	35-45	30	15.7	11	07/17/00	0.76
EWNA5	A	35-45	10	1.6	9	07/18/00	0.06
EWNA6	A	27-37	10	9.0	2.5	07/17/00	0.10
EWNA7	A	48-58	10	Out of service ^{g/}			
EWNA8	A	20-35	10	4.5	1.3	07/17/00	0.03
EWNA9	A	40-55	40	11.8	12	07/17/00	0.62
EWNA10	A	29-39	40	7.5	18	07/17/00	0.59
EWNB1	B	110-120	10	4.1	41	07/18/00	0.74
EWNB2	B	105-115	8	11.5	5.8	07/20/00	0.29
EWNB3	B	106-116	10	13.1	2.1	07/21/00	0.12
EWNB5	B	64-74	40	1.2	40	07/20/00	0.21
EWNB6	B	57.5-77.5	19	20.5	1.5	07/24/00	0.13
EWNC2R	C	75-95	40	37.3	12	07/11/00	1.96
EWNC3R	C	72-92	40	41.0	19	07/14/00	3.42
EWNC4R	C	87.8-97.8	40	40.1	3.9	07/14/00	0.69
Extraction Wells in Central Area							
EW CAB1	AB	28.1-33.1 & 44.7-49.7	40	12.8	38	07/14/00	2.13
EW CAB2	AB	29.6-49.8	30	11.4	8.8	07/14/00	0.44
EWCB2	B	81.8-91.8	30	50.5	19	07/19/00	4.21
EWCB3	B	55.3-59.7	30	23.5	49	07/20/00	5.05
EWCB4	B	82.1-91.9	30	48.1	16	07/20/00	3.38
EWCC1	C	135-144.9	60	81.6	54	07/13/00	19.33
EWCC2	C	98.3-108.3	30	51.7	2.9	07/13/00	0.66
EWCC3	C	128.1-137.9	60	91.4	26	07/07/00	10.42
EWCC4	C	100.8-110.8	60	109.5	6.7	07/13/00	3.22
Extraction Wells in South Balloon Area							
EWA1	A	20.7-30.7	10	2.1	12	10/21/99	0.11
EWA2	A	16-31.3	10	4.7	18	10/19/99	0.37
EWA3	A	15.4-30.8	10	1.4	78	04/18/00	0.48
EWA4	A	27-37.3	10	Out of service ^{h/}	< 0.3	07/23/98	
EWA5	A	29.6-39.5	10	0.02	100	07/18/00	0.01
EWA6	A	20-30	10	3.2	4.1	07/21/00	0.06
EWA7	A	27-37	10	2.3	28	04/18/00	0.28
EWA8	A	20.1-35.5	10	7.3	78	04/18/00	2.50
EWA9	A	25.4-35.4	10	13.4	3.8	04/18/00	0.22
EWA10	A	25.4-35.4	10	5.1	11	07/11/00	0.25
EWCA1	A	30-40	50	4.3	44	07/19/00	0.83
EWB1	B	67.1-77.4	20	19.7	73	07/17/00	6.31
EWB2	B	44.5-55	20	2.0	32	07/20/00	0.28
EWB3	B	39-49.3	20	Out of service ^{i/}			
EWCB1	B	48.8-58.8	50	12.1	92	04/13/99	4.88
EW C1	C	80.5-90.5	20	20.9	36	04/13/99	3.30
EW C2	C	91.5-102	20	36.6	16	04/18/00	2.57
EW C3	C	86-96	20	45.0	35	04/18/00	6.91

^{a/} Design details and well production rates for 1999 from Radian (1999g). Concentrations of TCE in extracted groundwater from Radian (2000c).
^{b/} ft bgs = feet below ground surface.
^{c/} gpm = gallons per minute.
^{d/} µg/L = micrograms per liter.
^{e/} Date = date of sample collection.
^{f/} lbs/year = pounds of trichloroethene (TCE) removed per year by an operating groundwater extraction well.
^{g/} Well EWNA7 was removed from service in the 4th quarter of 1997.
^{h/} Well EWA4 was removed from service in 1999.
^{i/} Well EWB3 was not in service in 1999.

1 The average concentration of TCE in extracted groundwater influent to the North
2 Balloon treatment plant was 16.6 µg/L during 1999, with a maximum-recorded influent
3 concentration of 29 µg/L. During the same period, the average influent concentrations of
4 PCE and DCE isomers were 0.66 µg/L and 0.83 µg/L, respectively. The total mass of
5 TCE, PCE, and DCE isomers removed from groundwater in the North Balloon area,
6 during the period October 1998 through September 1999, is estimated to have been 18.82
7 lbs, 0.53 lbs, and 0.63 lbs, respectively (Radian, 1999g). The 18.82 pounds of TCE
8 removed from groundwater in the North Balloon area in that period was about 10 lbs less
9 than the amount of TCE mass (29.2 lbs) removed from groundwater during the preceding
10 12-month period (October 1997 through September 1998). The current rate of TCE mass
11 removal at the North Balloon GWTP, estimated using average rates of groundwater
12 extraction reported for wells in the North Balloon, and the concentrations of TCE most
13 recently detected in samples of extraction-well effluent (Table 4.6, Columns 6 and 8), is
14 about 12 pounds per year (lbs/year).

15 Operation and maintenance issues affecting components of the North Balloon GWTP
16 include scaling of extraction wells, low rates of groundwater extraction, pressure surges
17 in water lines, and shorts in the electrical system resulting in well/treatment plant
18 downtime (Radian, 1999a; *ibid.*, 1999g). The OM&M contractor at DDJC-Sharpe (Tetra
19 Tech, Inc.) has completed a number of measures intended to improve the performance of
20 the North Balloon GWTP, including redevelopment and acid washing of selected
21 extraction wells, rehabilitation and/or replacement of pumps, installation of pressure
22 transducers, replacement of flow meters, and upgrading system control hardware and
23 software.

24 **4.2.1.2 Central Area GWTP System**

25 The Central Area groundwater ETI system consists of 9 extraction wells, a plant to
26 treat extracted groundwater, and water-disposal facilities. Design discharge rates for the
27 extraction wells range from 30 to 40 gpm for wells completed in the “A” and “B”
28 monitoring zones, and 30 to 60 gpm for wells completed in the “C” monitoring zone
29 (Table 4.6). Current actual production rates range from about 11 gpm to more than 100
30 gpm, with extraction wells completed in the “C” monitoring zone producing at the

1 highest rates. In 1998, the extraction system produced at an average rate of about 34 gpm
2 from wells completed in the “A” zone, and at an average rate of about 410 gpm from
3 wells completed in the “B” and “C” zones (Radian, 1999a). Average production rates in
4 1999 were about 36 gpm from wells completed in the “A” zone, and about 391 gpm from
5 wells completed in the “B” and “C” zones (Radian, 1999g).

6 As a consequence of elevated levels of arsenic in groundwater extracted from some
7 wells completed in the uppermost (“A”) monitoring zone in the Central Area,
8 groundwater from the “A” zone is managed separately from groundwater extracted from
9 the “B” and “C” zones. Groundwater extracted from the Central Area is directed to the
10 Central Area GWTP (Figure 4.10), which comprises two separate air-stripping treatment
11 trains (one system for “A”-zone groundwater and a second for groundwater from the “B”
12 and “C” zones), each consisting of twin, counter-flow stripping towers in series; two
13 chemical sequestration systems; a control building and ancillary equipment; two
14 percolation ponds; 10 injection wells; and a discharge pipeline to the Dynegy® plant. The
15 Central Area groundwater extraction and treatment system was originally designed for a
16 capacity of 75 gpm of water from the “A” zone and 500 gpm from the “B” and “C”
17 zones, but the “A”-zone treatment train typically operates at rates ranging from about 35
18 to 40 gpm, and the “B”/“C”-zone treatment train operates at rates ranging from about 350
19 to 400 gpm (Radian, 1999g).

20 The average concentrations of TCE in extracted groundwater influent to the Central
21 Area treatment plant are the highest at DDJC-Sharpe. The average concentration of TCE
22 in extracted groundwater influent to the “A”-zone treatment train was 64.3 µg/L during
23 1999, with a maximum-recorded influent concentration of 120 µg/L. During the same
24 period, the average concentration of TCE in extracted groundwater influent to the
25 “B”/“C”-zone treatment train was 27.7 µg/L, with a maximum-recorded influent
26 concentration of 43 µg/L. The total mass of TCE removed from “A”-zone groundwater
27 in the Central Area, during the period October 1998 through September 1999, is
28 estimated to have been 6.03 lbs; about 48 pounds of TCE was removed from groundwater
29 in the “B” and “C” zones during the same period (Radian, 1999g). The 54 pounds of
30 TCE removed from groundwater in the Central Area in that period was about 11 lbs less

1 than the amount of TCE mass (65.4 lbs) removed from groundwater in the preceding 12-
2 month period (October 1997 through September 1998). The current rate of TCE mass
3 removal at the Central Area GWTP, estimated using average rates of groundwater
4 extraction reported for wells in the Central Area, and the concentrations of TCE most
5 recently detected in samples of extraction-well effluent (Table 4.6, Columns 6 and 8), is
6 about 50 lbs/year.

7 Operation and maintenance issues affecting components of the Central Area GWTP
8 include scaling of extraction wells, low rates of groundwater extraction and injection,
9 pressure surges in water lines, and shorts in the electrical system resulting in
10 well/treatment plant downtime (Radian, 1999a; *ibid.*, 1999g). Recent efforts completed
11 by the OM&M contractor at DDJC-Sharpe to improve the performance of the Central
12 Area GWTP include redevelopment and acid washing of selected extraction wells,
13 rehabilitation and/or replacement of pumps, reduction of discharge to the percolation
14 ponds, replacement of chemical sequestrant feed tanks, and upgrading system control
15 hardware and software.

16 **4.2.1.3 South Balloon GWTP System**

17 The South Balloon groundwater ETI system consists of 18 extraction wells (16 of
18 which currently are in operation), and facilities to treat and manage extracted
19 groundwater. Design discharge rates for the extraction wells range from 10 to 20 gpm for
20 nearly all wells (Table 4.6). Current actual production rates range from 0 (3 wells were
21 off-line during much or all of 1999) to about 45 gpm, with extraction wells completed in
22 the "C" monitoring zone producing at the highest rates. In 1998, the extraction system
23 produced at an average rate of about 231 gpm; and the average production rate in 1999
24 was about 204 gpm (Radian, 1999a; *ibid.*, 1999g).

25 Groundwater extracted from the South Balloon area is directed to the South Balloon
26 GWTP (Figure 4.10). The South Balloon GWTP consists of twin, counter-flow stripping
27 towers in series; a chemical sequestration system; a control building and ancillary
28 equipment; and a discharge pipeline to the Dynegy® plant. The treatment system
29 currently operates at rates ranging from about 200 to 250 gpm (Radian, 1999g).

1 The average concentration of TCE in extracted groundwater influent to the South
2 Balloon treatment plant was 33.8 µg/L during 1999, with a maximum-recorded influent
3 concentration of 64 µg/L. During the same period, the average concentration of DCE
4 isomers in influent groundwater was 4.6 µg/L. The total mass of TCE and DCE isomers
5 removed from groundwater in the South Balloon area, during the period October 1998
6 through September 1999, is estimated to have been 30.18 lbs and 2.93 lbs, respectively
7 (Radian, 1999g). The 30.18 pounds of TCE removed from groundwater in the South
8 Balloon area in that period was about 20 lbs less than the amount of TCE mass (51.7 lbs)
9 removed from groundwater in the preceding 12-month period (October 1997 through
10 September 1998). The current rate of TCE mass removal at the South Balloon GWTP,
11 estimated using average rates of groundwater extraction reported for wells in the South
12 Balloon, and the concentrations of TCE most recently detected in samples of extraction-
13 well effluent (Table 4.6, Columns 6 and 8), remains at about 30 lbs/year.

14 Operation and maintenance issues affecting components of the South Balloon GWTP
15 include scaling of extraction wells, low rates of groundwater extraction, pressure surges
16 in water lines, and shorts in the electrical system resulting in well/treatment plant
17 downtime (Radian, 1999a; *ibid.*, 1999g). The OM&M contractor at DDJC-Sharpe has
18 completed a number of measures intended to improve the performance of the South
19 Balloon GWTP, including redevelopment and acid washing of selected extraction wells,
20 rehabilitation and/or replacement of pumps and pipelines, installation of pressure
21 transducers, replacement of flow meters, and upgrading system control hardware and
22 software.

23 **4.2.1.4 Water Management and Disposal**

24 Treated groundwater from the North and South Balloon GWTPs is discharged via the
25 facility storm drain system to the SSJIDC, which discharges into French Slough north of
26 the facility (Figure 4.10). Some of the treated groundwater may be diverted for beneficial
27 use by a neighboring co-generation plant (the Dynegy® plant); however, the plant is not
28 required to accept treated groundwater, and this disposal option is not regarded as reliable
29 for the long term. Treated groundwater from the Central Area GWTP is discharged to
30 on-Depot injection wells and percolation ponds, and can also be discharged to the

1 SSJIDC through the storm-drain system. However, discharge from the Central Area
2 treatment plant to the storm drain system is not often utilized, due to occasionally
3 elevated concentrations of arsenic in groundwater from Central Area extraction wells,
4 which is not removed during treatment. Only treated groundwater from the “B”/”C”
5 zones of the Central Area is disposed via injection wells; as a consequence of elevated
6 arsenic concentrations, treated groundwater from the “A” zone is returned to the
7 groundwater system in the shallow subsurface by discharging to percolation ponds for re-
8 infiltration. Treated water from the Central Area may also be diverted to the Dynegey®
9 pipeline (Radian, 1999g).

10 Discharge measurements at the treatment plants indicate that for the period October
11 1998 through September 1999, 86 percent of treated groundwater from the North Balloon
12 GWTP was discharged to the storm drain and 14 percent was diverted to the Dynegey®
13 line (Radian, 1999g). In the same period, all treated groundwater from the South Balloon
14 GWTP was diverted to the Dynegey® line and nearly all treated groundwater from the
15 Central Area GWTP was sent to the percolation ponds.

16 The design discharge rates of injection wells in the Central Area range from about 20
17 to 70 gpm (ETA, 1993). Although the current rates of injection attainable by individual
18 wells are not known, the rates at which treated groundwater can be disposed using
19 injection wells apparently have decreased substantially since the injection wellfield was
20 installed. In 1998, the rate of water disposal via all active injection wells in the Central
21 Area averaged about 160,000 gallons per month (equivalent to approximately 4 gpm)
22 (Radian, 1999a). The rate of injection-well disposal in 1999 averaged about 262,000
23 gallons per month (equivalent to approximately 6 gpm) (Radian, 1999g). Injection-well
24 efficiencies often decline through time, as a consequence of mechanical, hydraulic, or
25 geochemical factors (Driscoll, 1986). Injection wells that discharge water at high
26 velocities are mechanically inefficient, in that substantial head losses can occur in the
27 wellbore and adjacent receiving formation as a result of turbulent flow and friction.
28 Injection wells that are partially-penetrating (i.e., the completion interval of the well does
29 not extend through the full saturated thickness of the water-bearing zone) are
30 hydraulically inefficient, because of partial-penetration losses. Injection well efficiencies

1 can deteriorate as a consequence of geochemical reactions leading to formation of
2 precipitants in the wellbore or adjacent formation materials. Such reactions can occur as
3 a result of geochemical differences between the treated water and the ambient
4 groundwater in the injection zone, changes in pH and ORP of the water during the time
5 between extraction and re-injection, or changes in the temperature or pressure of the
6 water during treatment. For example, precipitation of calcite (calcium carbonate) can
7 result from changes in the partial pressure of carbon dioxide in solution during the time
8 between extraction and re-injection. The common occurrence of “scale” in groundwater
9 extraction wells and conveyance pipelines at DDJC-Sharpe suggests that calcium-
10 carbonate deposition may be a factor in the deterioration of injection-well performance.

11 **4.2.1.5 Estimated Costs Associated with Groundwater Remediation Systems**

12 The three GWTPs at DDJC-Sharpe were installed at different times (1986-87, 1989-
13 90, and 1994-95), and have been in operation for periods of time ranging from 6 to 14
14 years. Detailed information regarding the cost of installing the systems is not available,
15 and therefore cannot be used to estimate the overall costs associated with groundwater
16 remediation at DDJC-Sharpe. In any case, the costs of system installation are regarded as
17 “sunk costs” (Newnan, 1988), in that the systems have already been installed and are
18 operational, installation costs could not be recovered in the unlikely event that all
19 groundwater remediation activities were to cease, and potential improvements to the
20 current systems, as installed, will have no effect on the original costs of installation.

21 However, improvements in system efficiencies will affect costs associated with long-
22 term operation and maintenance (O&M) of the systems. Information provided by DDJC-
23 Sharpe (Mr. Ron Allen, 2000) indicates that base costs for O&M of the three
24 groundwater ETI systems at DDJC-Sharpe are approximately \$150,000 per year (in
25 current dollars). If additional, “optional” O&M services are provided, the annual O&M
26 costs increase, to approximately \$450,000 (in current dollars). “Optional” O&M services
27 include such activities as well redevelopment and rehabilitation, replacement of pumps,
28 acid-washing of transmission pipelines, and providing system inspections on a more
29 frequent basis. As is apparent from the preceding descriptions of the systems, these
30 “optional” services are probably necessary to maintaining the operational status of the

1 systems. Accordingly, the long-term costs associated with operation of the groundwater
2 ETI systems at DDJC-Sharpe will be evaluated using an annual O&M cost of \$450,000
3 (current dollars), equivalent to a monthly O&M cost of about \$37,500. If O&M costs are
4 prorated on a cost-per-well basis among the 42 currently-operating extraction wells, the
5 annual O&M cost per well is approximately \$10,700 (current dollars), equivalent to a
6 monthly O&M cost per well of about \$900. Costs associated with groundwater
7 monitoring are addressed in Section 4.3, and are specifically excluded from the annual
8 O&M costs.

9 **4.2.2 Evaluation of Groundwater Extraction System**

10 The primary RAO for groundwater at DDJC-Sharpe (Section 3.1.2) is to restore
11 groundwater to its highest beneficial use, defined by the Central Valley RWQCB to be
12 existing or potential beneficial use as a source of drinking water (California RWQCB,
13 1998). Preventing further contaminant migration to potential off-site exposure points and
14 receptors is a secondary objective of groundwater remediation.

15 Groundwater extraction and air-stripping treatment of extracted groundwater was
16 selected as the most appropriate remedy to achieve the RAOs for groundwater at DDJC-
17 Sharpe, and is currently being implemented at the North Balloon, Central Area, and
18 South Balloon. In general, two primary remediation objectives are associated with
19 conventional groundwater extraction (“pump-and-treat”) systems (NRC, 1994): removal
20 of contaminant mass from the subsurface, and establishing or maintaining hydraulic
21 control to restrict or prevent continued migration of dissolved contaminants in
22 groundwater. The effectiveness of the groundwater extraction systems, and of the
23 individual wells in each system, can be evaluated in terms of the two complementary
24 objectives – mass removal and plume containment. Although incremental improvements
25 in the effectiveness and efficiency of a groundwater extraction system may be achieved
26 through changes in well placement or depth intervals of extraction, the opportunities to
27 optimize the currently operating groundwater extraction system are restricted by the
28 physics of the system and the nature and distribution of contaminants in groundwater.

4.2.2.1 Mass Removal

The concentrations of TCE in groundwater at all locations beneath, and downgradient of DDJC-Sharpe must eventually decrease to levels below the ACL concentration (5 µg/L) if the primary RAO for groundwater at DDJC-Sharpe is to be achieved. During design of the groundwater ETI systems (ETA, 1993), it was estimated that ACL concentrations of TCE would be achieved at most locations in the groundwater system at DDJC-Sharpe in about 50 years, but that TCE could persist in groundwater at some locations, at concentrations greater than 5 µg/L, for a period of time greater than 100 years. Approximately 95 percent of the original mass of TCE in groundwater (estimated to be about 655 pounds) was predicted to be removed via groundwater ETI systems and natural-attenuation mechanisms within a 50-year period; however, at the conclusion of 100 years of operation, over 20 pounds of TCE was predicted to remain in groundwater at DDJC-Sharpe (ETA, 1993).

The rate of removal of contaminant mass can be estimated using

$$\text{Mass Removal Rate} = \frac{\text{Groundwater Extraction Rate}}{\times \text{Contaminant Concentration in Extracted Groundwater}} \quad \text{Equation 4-1}$$

with appropriate adjustment of units (e.g., conversion of gpm to liters per year). The amounts and rates of removal of contaminant mass can be calculated, using Equation 4-1, the monthly total volume of groundwater influent to each GWTP, and the historic concentrations of VOCs in extracted groundwater. Using information provided by Radian (2000c), Parsons calculated the monthly rates of mass removal by each GWTP, for the period 1995 through September 1999 (Table 4.7). (Reliable data for groundwater influent rates and concentrations of VOCs in the influent stream are not available for periods prior to 1995.) Since 1995, the groundwater ETI system in the North Balloon area has removed a cumulative total of over 100 pounds of TCE from groundwater (Table 4.7 and Figure 4.12). The Central Area groundwater ETI systems were placed in service in mid-1995, and since that time have removed cumulative totals of about 120 pounds of TCE from “A”-zone groundwater, and about 220 pounds of TCE from “B”/“C”-zone groundwater. During the same period, the groundwater ETI system in the South Balloon

TABLE 4.7												
SUMMARY OF CHEMICAL MASS REMOVAL, 1995 - 1999 ^{a/}												
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT												
DDJC-SHARPE, CALIFORNIA												
Month Year		North Balloon			Central Area				South Balloon			
		PCE ^{b/} (lbs) ^{f/}	TCE ^{c/} (lbs)	cis-1,2-DCE ^{d/} (lbs)	"A" Zone		"B"/"C" Zones		PCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	trans-1,2-DCE ^{e/} (lbs)
					TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)				
January	1995	0	1.96	0	g/				0	8.24	2.11	0.29
February	1995	0.05	2.35	0.11					0	6.94	1.95	0
March	1995	0.07	2.31	0.09					0.15	8.24	2.11	0
April	1995	0.58	1.67	0.09					0	6.00	1.23	0
May	1995	0	1.30	0.13					0	4.15	0.85	0
June	1995	0.06	1.48	0.10					0	4.90	1.07	0
July	1995	0.04	1.47	0.08					0	5.98	1.45	0
August	1995	0	1.13	0.04					0	5.10	1.16	0.65
September	1995	0	1.20	0.05					0	5.94	1.33	0
October	1995	0.03	1.45	0.09					0	5.19	0.96	0
November	1995	0.03	1.24	0.07					0	4.44	0.72	0
December	1995	0	1.12	0.02					0	5.13	0.68	0
Annual Totals		0.86	18.68	0.87					0.15	70.25	15.62	0.94
		PCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Carbon Tetrachloride (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Chloroform (lbs)
January	1996	0.05	1.03	0.05	6.15	0	5.83		0	6.81	1.11	0.03
February	1996	0.06	1.53	0.07	8.89	0.01	6.67		0.01	4.34	0.58	0.02
March	1996	0.06	2.24	0.02	11.07	0.01	9.10		0.03	6.98	0.72	0.05
April	1996	0.03	1.56	0.06	6.57	0	9.20		0.03	6.86	0.85	0.02
May	1996	0.03	2.70	0.03	10.83	0	8.59		0	8.44	1.48	0.02
June	1996	0.03	1.80	0.06	4.16	0	6.07		0.01	6.42	1.04	0.01
July	1996	0.04	2.26	0.05	7.45	0	6.11		0.01	5.55	1.08	0
August	1996	0.03	1.52	0.04	4.66	0	5.09		0.01	5.69	0.97	0.01
September	1996	0.04	1.46	0.04	4.60	0	4.62		0	5.18	0.85	0.03
October	1996	0.05	1.90	0.02	4.01	0	5.71		0	6.21	0.83	0.05
November	1996	0.04	1.21	0.04	3.65	0	4.20		0.03	4.54	0.88	0.02
December	1996	0.05	1.74	0.05	4.58	0	4.57		0	5.48	0.81	0
Annual Totals		0.51	20.95	0.53	76.62	0.02	75.76		0.13	72.50	11.20	0.26
		PCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Carbon Tetrachloride (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Chloroform (lbs)
January	1997	0	1.60	0	3.53	0	4.82		0	4.71	0.71	0
February	1997	0	1.00	0	1.53	0	5.04		0	5.18	0.72	0
March	1997	0.02	0.91	0.02	2.76	0	5.00		0	8.47	1.15	0
April	1997	0	0	0	2.38	0	5.54		0	6.00	0.83	0
May	1997	0	3.15	0	3.98	0	6.52		0	7.31	0.90	0
June	1997	0.08	2.52	0	2.48	0	5.65		0	5.12	0.72	0
July	1997	0	2.24	0.04	2.39	0	4.68		0	4.50	0.68	0
August	1997	0.02	2.05	0	2.13	0	4.60		0	4.03	0.43	0
September	1997	0	2.39	0.02	1.77	0	4.01		0	4.96	0.53	0
October	1997	0.105	3.11	0.142	2.152	0.028	5.10	0.291	0.171	5.609	0.737	0.171
November	1997	0.115	3.052	0.132	2.012	0.028	4.517	0.146	0.166	5.612	0.549	0.166
December	1997	0.251	3.456	0.251	1.624	0.027	5.386	0.295	0.178	5.737	0.543	0.178
Annual Totals		0.591	25.48	0.605	28.74	0.083	60.86	0.732	0.515	67.24	8.50	0.515
		PCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Carbon Tetrachloride (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Chloroform (lbs)
January	1998	0.131	3.059	0.162	1.234	0.043	3.497	0.245	0.163	4.064	0.410	0.163
February	1998	0	2.049	0.043	0.972	0.059	2.738	0.233	0.139	2.536	0.333	0.139
March	1998	0.177	1.247	0.177	1.140	0.071	3.419	0.279	0.189	3.723	0.311	0.189
April	1998	0.402	2.347	0.402	1.203	0.062	3.912	0.462	0.267	3.903	0.497	0.267
May	1998	0.303	2.613	0.333	0.999	0.063	4.408	0.333	0.386	3.989	0.446	0.386
June	1998	0.031	2.685	0.061	1.250	0.060	4.723	0.326	0.269	4.889	0.646	0.269
July	1998	0	2.563	0.032	1.285	0.061	4.859	0.335	0.277	4.554	0.477	0.277
August	1998	0.225	1.349	0.225	0.526	0.031	4.238	0.332	0.171	3.796	0.444	0.171
September	1998	0.110	1.618	0.125	0	0	4.233	0.308	0.251	3.319	0.374	0.251
October	1998	0.073	1.900	0.101	0		4.910			3.290	0.460	
November	1998	0.061	1.310	0.070	0		4.160			5.230	0.690	
December	1998	0.063	1.260	0.067	0		2.910			3.860	0.590	
Annual Totals		1.58	24.00	1.80	8.61	0.45	48.01	2.85	2.11	47.15	5.68	2.11
		PCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Carbon Tetrachloride (lbs)	TCE (lbs)	cis-1,2-DCE (lbs)	Chloroform (lbs)
January	1999	0.063	1.22	0.034	0		4.01			3.08	0.34	
February	1999	0.06	1.37	0.064	0		3.92			1.16	0.13	
March	1999	0.058	1.45	0.068	1.36		5.20			2.91	0.28	
April	1999	0.06	1.38	0.064	1.25		4.56			2.71	0.26	
May	1999	0.066	1.77	0.083	0.98		4.86			2.06	0.20	
June	1999	0	1.17	0.035	0.76		3.27			1.72	0	
July	1999	0	1.05	0	0.68		3.31			1.25	0	
August	1999	0.029	2.72	0.052	0.32		2.42			0.61	0	
September	1999	0	2.22	0	0.68		4.44			2.31	0	
October	1999											
November	1999											
December	1999											
Annual Totals		0.336	14.35	0.400	6.03		35.99			17.81	1.21	
Totals 1995 - 1999		3.87	103.5	4.20	120.0	0.55	220.6	3.59		275.0	42.21	

^{a/} Monthly total chemical mass removal for each groundwater treatment plant reported by Radian (2000c).

^{b/} PCE = tetrachloroethene.

^{c/} TCE = trichloroethene.

^{d/} *cis*-1,2-DCE = *cis*-1,2-dichloroethene.

^{e/} *trans*-1,2-DCE = *trans*-1,2-dichloroethene.

^{f/} lbs = pounds.

^{g/} A blank entry indicates that the groundwater treatment plant was not operational, or that chemical mass removal was not reported during that period.

1 **Figure 4.12 Cumulative TCE Mass Removal – 1995 – 1999**

2 (Oversize 11 x 17)

3

1 area has removed a cumulative total of approximately 275 pounds of TCE from
2 groundwater. Much lower amounts of other VOCs have been removed from groundwater
3 since 1995 (Table 4.7).

4 If the mass of TCE originally present in groundwater were known, and the current
5 rates of removal of TCE mass could be sustained, the removal rates could be used to
6 estimate the length of time required to achieve RAOs for groundwater at DDJC-Sharpe
7 by removing all TCE mass from the groundwater system. Unfortunately, the cumulative
8 total TCE mass removed by the groundwater ETI systems as of September 1999 (about
9 719 pounds; Table 4.7) exceeds the amount of TCE mass originally estimated to be
10 present in groundwater (about 655 pounds; ETA, 1993). Apparently, the concentrations
11 of TCE dissolved in groundwater were used to estimate the amount of TCE mass
12 remaining in the subsurface at DDJC-Sharpe (ETA, 1993). In reality, much of the TCE
13 mass in the subsurface is probably sorbed to soil, or has diffused into isolated pore spaces
14 or the soil matrix (Appendix B). In this situation, the total mass of TCE in the subsurface
15 is difficult or impossible to estimate.

16 Furthermore, it is unlikely that the current rates of removal of TCE mass will be
17 sustained for long periods of time, because decreases in the rate of removal of
18 contaminant mass from groundwater systems commonly occur through time with active
19 groundwater extraction systems (NRC, 1994). Since 1995, contaminant mass has been
20 removed from groundwater in the North Balloon area and from "B"/"C"-zone
21 groundwater in the Central Area at relatively constant rates, as indicated by the constant
22 slopes of the cumulative mass-removal curves (Figure 4.12). The rate of contaminant
23 mass removal from groundwater in the South Balloon area was relatively constant from
24 1995 through late 1998, but decreased in 1999 (as indicated by the progressive flattening
25 of the slope of the mass-removal curve); and the rate of contaminant mass removal from
26 "A"-zone groundwater in the Central Area has been progressively decreasing, and may
27 have become asymptotic (indicated by the nearly flat slope of the curve in 1998 and
28 1999) (Figure 4.12). In 1996, the Central Area GWTP removed approximately 77
29 pounds of TCE from "A"-zone groundwater (Table 4.7), but since that time, the annual
30 rate of TCE removal has decreased, to approximately 10 pounds per year. At some point

1 in the future, the mass-removal rates probably will also decline for the systems in the
2 North Balloon area and the “B”/“C”-zone system in the Central Area. To some extent,
3 the observed decline in rates of TCE mass removal may be due to decreases in the rate of
4 groundwater extraction in the South Balloon and Central Area (c.f., Equation 4.1).
5 However, most of the observed decline in rates of TCE mass removal is probably a result
6 of an overall decrease in the concentrations of TCE in extracted groundwater. For
7 example, the concentration of TCE in extracted groundwater influent to the Central Area
8 “A”-zone GWTP was 746 µg/L in April 1996 (Radian, 2000a). By August 2000, the
9 concentration of TCE in extracted groundwater influent to the Central Area “A”-zone
10 GWTP was 33 µg/L – a decrease in influent concentrations of a factor of over 20 (Figure
11 4.13).

12 This decline in contaminant concentrations and associated decrease in mass-removal
13 rates is likely due to contaminant sorption/desorption phenomena -- contaminants in the
14 subsurface tend to diffuse into inaccessible soil pore spaces and become very strongly
15 sorbed, particularly to fine-grained soil particles. As water moves through the soil,
16 sorbed contaminants desorb only slowly from the soil into groundwater; and much of the
17 contaminant mass remains sorbed to soil particles, as a consequence of equilibrium
18 partitioning between groundwater and soil (Appendix B). Under these conditions, the
19 slow desorption of contaminant mass from soil or diffusion of contaminant mass from the
20 soil matrix into groundwater is capable of functioning as a long-term source of
21 contaminants in groundwater. In recognition of the problems associated with sorption of
22 contaminants to soil and the slow rates of desorption/dissolution reactions, USEPA
23 (1992) issued a directive regarding groundwater remediation at Superfund sites, which
24 stated that groundwater pump-and-treat systems usually cannot remediate dissolved
25 contaminant concentrations to levels below typical site remediation goals for
26 groundwater. The National Research Council (NRC, 1994) further stated that:

- 27 1. Groundwater extraction is generally ineffective for restoring groundwater
28 quality to drinking-water standards, primarily as a result of the decreasing rates
29 of contaminant desorption from within soil particles into groundwater.
30

1

2 **Figure 4.13 TCE Concentrations in Extracted Groundwater Influent to Central**
3 **Area “A”-Zone GWTP**

4

2. Most aquifers are heterogeneous and have low-permeability zones where contaminants become immobilized. Groundwater pumping causes preferential flow of groundwater in zones of high permeability, resulting in the trapping of even highly soluble contaminants in low-permeability zones.

As a direct consequence of these limitations, groundwater extraction systems are generally ineffective at removing contaminant mass from the subsurface.

Rather than attempting to estimate the total mass of TCE remaining in groundwater at DDJC-Sharpe and comparing the total remaining TCE mass with current mass-removal rates, Parsons used an alternative approach to develop estimates of the total length of time required to attain the ACL concentration for TCE in groundwater (5 µg/L) throughout the North Balloon, South Balloon, and Central Area plumes. Plots were generated to show the concentrations of TCE in groundwater samples from individual extraction wells through time (Figures 4.14, 4.15, and 4.16). The trends in concentrations of TCE in groundwater samples from several of the extraction wells in the North Balloon, Central Area, and South Balloon appear to be decreasing through time, indicating that TCE concentrations in groundwater in the vicinity of each of these wells also have been decreasing.

The temporal concentration data for the extraction wells displaying trends of decreasing concentrations were fitted with first-order equations, and the first-order curves were projected through time until they intersected the cleanup goal for TCE in groundwater (the ACL concentration of 5 µg/L). Assuming that the concentrations of TCE in groundwater samples from these wells continue to decrease through time, and that the trends of decreasing concentrations continue to approximate first-order processes, this procedure can provide an estimate of the length of time required to achieve cleanup goals in groundwater at each location.

Cleanup goals for TCE in groundwater already have been attained at several locations at DDJC-Sharpe. The available concentration data for wells EWNA6, EWNA8, EWNB3, EWNB6, and EWNC4R in the North Balloon area, well EWCC2 in the Central Area, and well EWA3 in the South Balloon area, indicate that the concentrations of TCE

1

2 **Figure 4.14a Temporal Trends and Projected Cleanup Times for TCE – North**
3 **Balloon Wells**

4 (Oversize 11 x 17)

5

1 **Figure 4.14b Temporal Trends and Projected Cleanup Times for TCE – North**
2 **Balloon Wells**

3 (Oversize 11 x 17)

4

1 **Figure 4.15 Temporal Trends and Projected Cleanup Times for TCE – Central**
2 **Area Wells**

3 (Oversize 11 x 17)

4

1 **Figure 4.16a Temporal Trends and Projected Cleanup Times for TCE – South**
2 **Balloon Wells**

3 (Oversize 11 x 17)

4

1 **Figure 4.16b Temporal Trends and Projected Cleanup Times for TCE – South**
2 **Balloon Wells**

3 (Oversize 11 x 17)

4

1 in extracted groundwater at these locations are consistently below the ACL (Tables 4.8,
2 4.9, and 4.10). The projected cleanup dates are listed in the Tables for the other
3 extraction wells having apparent temporal trends in TCE concentrations. It is not
4 possible to use this estimation method to project groundwater cleanup dates at those well
5 locations having no apparent temporal trend in TCE concentrations (e.g., wells EWNA2
6 in the North Balloon, EWCC3 in the Central Area, and EWA5 in the South Balloon;
7 Figures 4.14, 4.15, and 4.16).

8 Application of this procedure assumes that no additional contaminant mass is
9 being/will be introduced to groundwater system at DDJC-Sharpe. However, slow
10 desorption of VOCs from soils in the groundwater zone represents a potential long-term,
11 continuing source of contaminants in groundwater. Therefore, although application of
12 the trend-projection technique described above can be used to predict that the ACL
13 concentration for TCE in groundwater at OU1 will be achieved at most locations no
14 earlier than about 2074 (c.f. extraction well EWCB1 in the South Balloon; Table 4.10), it
15 seems likely that a somewhat longer (though unknown) period of time will actually be
16 required. This possibility is reinforced by the lack of apparent temporal trends in TCE
17 concentrations in groundwater samples from 21 of the 42 currently-operating extraction
18 wells (Tables 4.8, 4.9, and 4.10).

19 The costs to date associated with groundwater remediation at DDJC-Sharpe can be
20 estimated, using information regarding the annual O&M costs of the current groundwater
21 ETI systems (Section 4.2.1.4). The costs of system installation are not included in
22 remediation cost estimates, because installation costs are regarded as “sunk costs”. The
23 annual costs associated with operation of the groundwater ETI systems at DDJC-Sharpe
24 are about \$450,000 (current dollars), equivalent to a monthly O&M cost of about
25 \$37,500. Reliable information regarding the removal of TCE mass by the groundwater
26 ETI systems is available only for the period since 1995 (Table 4.7); therefore, for the
27 purpose of developing a groundwater remediation cost estimate, system O&M costs are
28 assumed to accrue only since January 1995. If the costs of system installation, and
29 system O&M prior to January 1995 are neglected, and O&M costs since January 1995
30 have accrued at a rate of \$37,500 per month (in constant, year 2000 dollars) then the costs

TABLE 4.8
PROJECTED CLEANUP DATES^{a/}
FOR
GROUNDWATER EXTRACTION WELLS
IN THE NORTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Projected Cleanup Date
EWNA1	1Q2002 ^{b/}
EWNA2	No trend
EWNA3	No trend
EWNA4	No trend
EWNA5	No trend
EWNA6	Currently below ACL concentration ^{c/} for TCE
EWNA8	Currently below ACL concentration for TCE
EWNA9	3Q2010
EWNA10	4Q2040
EWNB1	No trend
EWNB2	No trend
EWNB3	Currently below ACL concentration for TCE
EWNB5	No trend
EWNB6	Currently below ACL concentration for TCE
EWNC2R	1Q2005
EWNC3R	No trend
EWNC4R	Currently below ACL concentration for TCE

^{a/} Approximate cleanup dates projected using temporal trends in TCE concentrations.

^{b/} 1Q2002 = first quarter of 2002 (typical).

^{c/} Aquifer cleanup level (ACL) concentration of TCE is 5 micrograms per liter (µg/L).

TABLE 4.9
PROJECTED CLEANUP DATES^{a/}
FOR
GROUNDWATER EXTRACTION WELLS
IN THE CENTRAL AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Projected Cleanup Date
EW CAB1	2Q2002 ^{b/}
EW CAB2	1Q2001
EW CB2	No trend
EW CB3	1Q2001
EW CB4	1Q2012
EW CC1	No trend
EW CC2	Currently below ACL concentration ^{c/} for TCE
EW CC3	No trend
EW CC4	1Q2000

^{a/} Approximate cleanup dates projected using temporal trends in TCE concentrations.

^{b/} 2Q2002 = second quarter of 2002 (typical).

^{c/} Aquifer cleanup level (ACL) concentration of TCE is 5 micrograms per liter (µg/L).

TABLE 4.10
PROJECTED CLEANUP DATES^{a/}
FOR
GROUNDWATER EXTRACTION WELLS
IN THE SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Projected Cleanup Date
EWA1	No trend
EWA2	1Q2003 ^{b/}
EWA3	Currently below ACL concentration ^{c/} for TCE
EWA5	No trend
EWA6	No trend
EWA7	No trend
EWA8	2Q2001
EWA9	3Q2004
EWA10	No trend
EWCA1	No trend
EWB1	No trend
EWB2	No trend
EWCB1	4Q2074
EWC1	3Q2007
EWC2	No trend
EWC3	No trend

^{a/} Approximate cleanup dates projected using temporal trends in TCE concentrations.

^{b/} 1Q2003 = first quarter of 2003 (typical).

^{c/} Aquifer cleanup level (ACL) concentration of TCE is 5 micrograms per liter (µg/L).

2 of groundwater remediation for the period January 1995 through December 1999 are
3 estimated to be about \$2.2M. In that period, the three groundwater ETI systems removed
4 an estimated 720 pounds of TCE mass, at a cost per pound of TCE removed of about
5 \$3,100.

6 Long-term O&M costs for the current groundwater extraction system can be projected
7 into the future (Figure 4.17) using the previously derived projected cleanup dates for the
8 three groundwater ETI systems (Figures 4.14, 4.15, and 4.16). Estimates of future costs

1

2 **Figure 4.17 Cumulative TCE Mass Removal and Projected Cumulative Costs**
3 **Through Time**

4

1 for the systems were developed by assuming that the 7 wells at which the ACL
2 concentration of TCE has been attained (wells EWNA6, EWNA8, EWNB3, EWNB6,
3 and EWNC4R in the North Balloon area, well EWCC2 in the Central Area, and well
4 EWA3 in the South Balloon area; Tables 4.8, 4.9, and 4.10) are removed from service in
5 1Q2001 and will remain out of service indefinitely; and that other wells will be removed
6 from service at the time they are projected to achieve cleanup goals (e.g., well EWNA1
7 will be removed from service in 1Q2002, having achieved the ACL concentration for
8 TCE). After a well has been removed from service, the monthly O&M costs associated
9 with operation of that well (about \$900 per month in constant [year 2000] dollars; Section
10 4.2.1.4) were assumed to cease, and were removed from the cumulative cost estimate.
11 Well EWCB1 is projected to remain in service for the longest period of time (through
12 4Q2074); this was assumed to represent the period of time through which elements of the
13 groundwater ETI systems would remain active. TCE concentrations in groundwater
14 extracted by 21 of the existing wells display no apparent temporal trends in TCE
15 concentrations; these wells also were assumed to remain active through 4Q2074.

16 Cumulative costs for system operation projected 10 years into the future (2011) are
17 estimated to be approximately \$5.7M (Figure 4.17). If elements of the groundwater ETI
18 systems remain in operation through 4Q2074, the cumulative O&M costs associated with
19 groundwater remediation at DDJC-Sharpe, for the period 1995 through 2074, are
20 estimated to total approximately \$21M. Because the rates of removal of TCE mass from
21 groundwater of the North Balloon and the "B"/"C" zone in the Central Area are unlikely
22 to remain constant through long periods (Figure 4.13), it is not possible to project TCE
23 mass removal.

24 It may be possible to evaluate the effectiveness of the complete extraction system by
25 examining the effectiveness of individual wells. The recent production history of all
26 operating extraction wells at DDJC-Sharpe is presented in Table 4.6, together with the
27 concentrations of TCE detected in the discharge effluent of individual wells. Effluent
28 TCE concentrations were most recently measured in April and October 1999 (wells
29 EWCB1, EWC1, EWA1, and EWA2) and April and July 2000 (all other wells).
30 Examination of current annual rates of TCE removal for individual wells (Table 4.6,

Column 8) indicates that more than 80 percent of TCE mass removed from groundwater on an annual basis is being extracted by just 12 wells (well EWNC3R in the North Balloon; wells EWCB2, EWCB3, EWCB4, EWCC1, EWCC3, and EWCC4 in the Central Area; and wells EWB1, EWCB1, EWC1, EWC2, and EWC3 in the South Balloon [Figure 4.18]).

Examination of rates of removal of TCE mass indicates that significant removal (greater than about one pound per year) is occurring at 3 wells in the North Balloon area (Table 4.11 and Figure 4.18), at 7 of the 9 wells in the Central Area (Table 4.12), and at 6 wells in the South Balloon area (Table 4.13). Six wells in the North Balloon area, one well in the Central Area, and one well in the South Balloon area are considered to be “marginal”, producing between 0.5 and 1 pound of TCE per year. The remaining wells are considered to be ineffective, removing less than 0.5 pound of TCE per year.

Significant mass removal at wells EWB1, EWC1, EWC2, EWC3, EWCB1, EWCB3, and EWNC3R is accomplished because these wells collect groundwater at moderate rates (20 to 40 gpm) and extract TCE at moderate concentrations (16 µg/L to about 90 µg/L). By contrast, wells EWCB2, EWCB4, EWCC1, EWCC3, and EWCC4 accomplish mass removal by extracting TCE at relatively low concentrations (6.7 to about 50 µg/L), while extracting groundwater at relatively high rates (about 50 to 100 gpm). In general, the extraction wells having TCE at the highest concentrations in extracted groundwater are capable of producing groundwater only at low rates (c.f., wells EWA3, EWA5, and EWA8; Table 4.6). This provides confirmation of the observation (NRC, 1994) that in heterogeneous water-bearing units, contaminants become immobilized in low-permeability zones, and that groundwater extraction causes preferential flow of groundwater in zones of higher permeability. Virtually no mass removal is occurring at wells EWNA5, EWNA6, EWNA8, EWNB3, EWNB6, EWA1, EWA5, or EWA6 (Table 4.11, Table 4.13, and Figure 4.18), as a consequence of low rates of groundwater withdrawal, low TCE concentrations in extracted groundwater, or both.

1

2 **Figure 4.18 Annual Rates of TCE Mass Removal by Well**

3 (Oversize 11 x 17)

4

TABLE 4.11
RELATIVE EFFECTIVENESS OF GROUNDWATER EXTRACTION WELLS
IN THE NORTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Approximate Removal Rate of TCE ^{a/} (lbs/year) ^{b/}	Relative Effectiveness		
		Effective ^{c/}	Marginal ^{d/}	Poor ^{e/}
EWNA1	0.20			✓
EWNA2	1.15	✓		
EWNA3	0.92		✓	
EWNA4	0.76		✓	
EWNA5	0.06			✓
EWNA6	0.10			✓
EWNA8	0.03			✓
EWNA9	0.62		✓	
EWNA10	0.59		✓	
EWNB1	0.74		✓	
EWNB2	0.29			✓
EWNB3	0.12			✓
EWNB5	0.21			✓
EWNB6	0.13			✓
EWNC2R	1.96	✓		
EWNC3R	3.42	✓		
EWNC4R	0.69		✓	

^{a/} Rates of removal of TCE mass calculated using average groundwater extraction rates for 1999, and the concentration of TCE most recently detected in groundwater extracted by the well (Table 4.6).

^{b/} lbs/year = pounds per year.

^{c/} Individual well that removes TCE at a rate of 1.0 lb/year or greater.

^{d/} Individual well that removes TCE at a rate between 0.5 and 1.0 lb/year.

^{e/} Individual well that removes TCE at a rate less than 0.5 lb/year.

TABLE 4.12
RELATIVE EFFECTIVENESS OF GROUNDWATER EXTRACTION WELLS
IN THE CENTRAL AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Approximate Removal Rate of TCE ^{a/} (lbs/year) ^{b/}	Relative Effectiveness		
		Effective ^{c/}	Marginal ^{d/}	Poor ^{e/}
EW CAB1	2.13	✓		
EW CAB2	0.44			✓
EW CB2	4.21	✓		
EW CB3	5.05	✓		
EW CB4	3.38	✓		
EW CC1	19.33	✓		
EW CC2	0.66		✓	
EW CC3	10.42	✓		
EW CC4	3.22	✓		

^{a/} Rates of removal of TCE mass calculated using average groundwater extraction rates for 1999, and the concentration of TCE most recently detected in groundwater extracted by the well (Table 4.6).

^{b/} lbs/year = pounds per year.

^{c/} Individual well that removes TCE at a rate of 1.0 lb/year or greater.

^{d/} Individual well that removes TCE at a rate between 0.5 and 1.0 lb/year.

^{e/} Individual well that removes TCE at a rate less than 0.5 lb/year.

1

2

TABLE 4.13
RELATIVE EFFECTIVENESS OF GROUNDWATER EXTRACTION WELLS
IN THE SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Extraction Well	Approximate Removal Rate of TCE ^{a/} (lbs/year) ^{b/}	Relative Effectiveness		
		Effective ^{c/}	Marginal ^{d/}	Poor ^{e/}
EWA1	0.11			✓
EWA2	0.37			✓
EWA3	0.48			✓
EWA5	0.01			✓
EWA6	0.06			✓
EWA7	0.28			✓
EWA8	2.50	✓		
EWA9	0.22			✓
EWA10	0.25			✓
EWCA1	0.83		✓	
EWB1	6.31	✓		
EWB2	0.28			✓
EWCB1	4.88	✓		
EW C1	3.30	✓		
EW C2	2.57	✓		
EW C3	6.91	✓		

^{a/} Rates of removal of TCE mass calculated using average groundwater extraction rates for 1999, and the concentration of TCE most recently detected in groundwater extracted by the well (Table 4.6).

^{b/} lbs/year = pounds per year.

^{c/} Individual well that removes TCE at a rate of 1.0 lb/year or greater.

^{d/} Individual well that removes TCE at a rate between 0.5 and 1.0 lb/year.

^{e/} Individual well that removes TCE at a rate less than 0.5 lb/year.

3 The potential effectiveness of extraction wells was also evaluated, by examining their
4 locations with respect to the extent of TCE in groundwater, as defined by the 5 µg/L
5 isoconcentration isopleth in 3Q99 (Figure 2.13). An extraction well located outside of

1 the TCE plume is intuitively considered to be less effective in removing TCE mass than a
2 well located within the plume. In the North Balloon area, 4 wells (wells EWNA8,
3 EWNB3, EWNB6, and EWNC4R) are situated outside of the TCE plumes. Three of
4 these wells (wells EWNA8, EWNB3, and EWNB6) extract less than 0.5 pound of TCE
5 per year combined. In the South Balloon area, well EWCA1 is situated outside of the
6 TCE plume, and contributes less than one pound per year to TCE mass removal.

7 There have been numerous attempts throughout North America to restore
8 contaminated groundwater using groundwater extraction-and-treatment technology
9 (NRC, 1994; Pankow and Cherry, 1996). Groundwater restoration using extraction-and-
10 treatment systems is simple in concept, but in practice there are several factors that
11 commonly extend the time period needed to attain cleanup goals throughout the plume,
12 particularly if (as at DDJC-Sharpe) the goals specified are in the $\mu\text{g/L}$ ranges typical of
13 MCLs. These factors include slow desorption of contaminants from the soil matrix, and
14 slow release of contaminants by diffusion from low-permeability strata or from “dead-
15 end” pore spaces, and from the solid matrix. In a situation where much of the
16 contaminant mass is located in the lower-permeability parts of a water-bearing unit, slow
17 diffusion of contaminants out of these zones causes contaminant concentrations in the
18 plume to approach the required restoration levels only very slowly.

19 Furthermore, the amount of mass in the source zone(s) at these sites is often many
20 times greater than the amount of dissolved contaminant mass removed annually by
21 groundwater extraction, indicating that a period of many years may be required for
22 successful restoration of groundwater by removing contaminant mass. The rate of mass
23 removal at some sites can be increased by adding more wells in or near the source
24 zone(s), but the increase in the rate of mass removal will not be proportional to the
25 increase in groundwater extraction, as a consequence of limitations imposed by
26 desorption and diffusion kinetics, and because contaminated water will be diluted with
27 clean water drawn from water-bearing units outside of the source zone (Pankow and
28 Cherry, 1996).

1 The primary capabilities that groundwater extraction-and-treatment systems offer at
2 most sites are hydraulic control of the dissolved contaminant plume, and/or containment
3 of the source zone. Therefore, the preferred strategy for such sites is to pump at the
4 lowest rate necessary to achieve the desired degree of capture of the contaminant flux
5 from the source zone(s). The rate of contaminant mass removal is then equal to or only
6 slightly greater than the mass flux emanating from the source zone under natural
7 conditions. Therefore, plume containment is the primary focus of RPO evaluation of the
8 groundwater extraction system at DDJC-Sharpe, as discussed in the following subsection.

9 **4.2.2.2 Plume Containment**

10 **Numerical Model of Groundwater Movement and Contaminant Migration**

11 In conjunction with the RPO Phase II evaluation of remediation systems at DDJC-
12 Sharpe, Parsons reviewed a numerical model of groundwater flow and contaminant
13 migration, recently developed by the USACE Waterways Experiment Station (WES), to
14 evaluate the potential applicability of the model in assisting the optimization of
15 groundwater ETI systems in the North Balloon, Central Area, and South Balloon. The
16 WES modeling effort was undertaken during the period 1997 to March 2000 (USACE,
17 2000), to develop a tool to support the management of remediation activities at DDJC-
18 Sharpe and to evaluate the fate of contaminants in groundwater with the objective of
19 improving hydraulic containment/plume capture.

20 In constructing the numerical model, WES utilized the Groundwater Modeling System
21 (GMS) developed by the U.S. Department of Defense (USDOD) (USDOD, 1996). Based
22 on geometric considerations, the hydrogeologic features of the groundwater system, and
23 design details of the current remediation systems, the finite-element code FEMWATER
24 (a module of GMS) was selected for use at DDJC-Sharpe. FEMWATER (Lin *et al.*,
25 1996) is a 3-dimensional numerical model for use in evaluating groundwater movement
26 and contaminant migration, and can be used to simulate groundwater movement and
27 contaminant fate processes in fully- or variably-saturated porous media.

28 A three-dimensional finite-element mesh was generated for the numerical model, and
29 provided the basic geometric framework within which the model was constructed

(USACE, 2000). The modeled area was bounded by Louise Avenue to the south, Durham Ferry Road to the east, Highway I-5 to the west, and a north boundary located 2,500 feet north of Roth Road (Figure 4.19), and was selected on the basis of hydrologic features (extraction wells, canals, stormwater lagoons, hydraulic gradients) and the extent of contaminants in groundwater. The model was extended vertically from ground surface to a depth of about 250 feet bgs (elevation of 220 feet below mean sea level [bmsl]), corresponding to the upper contact of the Corcoran Clay at the base of monitoring zone “D” (Sections 2.2.3.2 and 2.2.3.3). The mesh was constructed in 11 layers, with 3 layers representing the unsaturated zone, 2 layers representing each of the “A” and “B” monitoring zones, one layer representing the “C” monitoring zone, and one layer representing the “D” monitoring zone (Figure 4.20). The vertical extent and layering of the mesh was based on local hydrostratigraphy, as interpreted from borehole data, and was sufficiently discretized to enable much of the heterogeneity in the subsurface to be represented, including the laterally and vertically discontinuous nature of interbedded sands, silts, and clays (Sections 2.2.3.2 and 2.2.3.3). The finite-element mesh that was eventually used in the numerical model consisted of 187,902 elements connected by 102,996 nodes (Figure 4.21).

Boundary conditions, and hydraulic properties of the various zones in the water-bearing unit, were assigned as model input, in order to define the model domain and the hydrogeologic characteristics of the subsurface. Boundary conditions at the edges of the model (Figure 4.22) were assigned as specified (“constant”) heads (Dirichlet boundary condition) based on hydraulic potentials (“heads”) thought to be representative of pre-remediation (natural, or “static”) conditions in the groundwater system. The SSJDC, which borders the eastern side of the DDJC-Sharpe, also was simulated using specified heads (Figure 4.22). The base of the mesh was treated as an impermeable boundary.

Extraction wells were simulated as negative fluxes assigned to specific nodes or columns of nodes (“sinks”). Injection wells were not simulated.

Hydraulic conductivity values derived from the results of aquifer tests were assigned to each layer. Horizontal hydraulic conductivity was assumed to be isotropic and

1

2 **Figure 4.19 Modeled Area and Well Locations**

3

1 **Figure 4.20 Oblique View of 3-D Finite-Element Mesh**

2

1 **Figure 4.21 Plan View of 3-D Finite-Element Mesh**

2

1 **Figure 4.22 Model Boundary Conditions**

2

uniform throughout each model layer. A value of 9.6 ft/day was assigned to model layers representing the unsaturated zone and the “A” monitoring zone; values of 4.8 ft/day, 48 ft/day, and 96 ft/day were assigned to the layers representing the “B”, “C”, and “D” monitoring zones, respectively. In order to represent vertical anisotropy, vertical hydraulic conductivity values were assumed to be one-tenth the value of horizontal hydraulic conductivity in layers representing the unsaturated zone, and the “A” and “B” monitoring zones; and were assumed to be one-twentieth the value of horizontal hydraulic conductivity in the “C” and “D” monitoring zones.

After the finite-element model had been constructed, it was calibrated and verified. Model calibration consisted of adjusting model input data – primarily hydraulic conductivity and boundary conditions – until the heads (i.e., groundwater hydraulic potentials) and fluxes (rates of groundwater movement and recharge or discharge) reasonably replicated known or assumed conditions. Steady-state calibration was conducted by attempting to match actual groundwater levels measured in October 1991, and August-September 1998, with model-simulated hydraulic potentials. During calibration, it was found that groundwater levels in the vicinity of the SSJDC were poorly replicated by the model. This problem was partially corrected by adjusting the specified-head boundary used to simulate the canal.

When a steady-state calibration had been achieved, a limited transient verification also was completed, in order to evaluate the capability of the numerical model to replicate the response of the groundwater system to historical hydraulic stresses. Transient verification was conducted by simulating a historic pumping test of a municipal-supply well (well PW5; Figure 4.19) near the southeast corner of DDJC-Sharpe. Verification consisted of attempting to match the observed changes in groundwater elevations in the vicinity of the pumping well with the hydraulic potentials generated by the numerical model as a simulated hydraulic stress was applied. As is normally the case, some additional refinement of the hydraulic parameters was conducted during transient verification. In addition, certain effects associated with the model boundaries were noted during transient verification.

1 After the numerical model was judged to be calibrated and verified, WES completed
2 two predictive simulations, to evaluate the possible interactions of the dissolved CAH
3 plumes in the North Balloon and South Balloon with actual and proposed supply wells,
4 and to evaluate water-disposal strategies and the potential effects of various disposal
5 alternatives on hydraulic containment and capture of the dissolved CAH plumes. During
6 the evaluation of water management and disposal strategies, additional percolation ponds
7 for disposal of treated groundwater were simulated, and their effects on the dissolved
8 CAH plumes were examined. The numerical model also was used to evaluate plume
9 capture by the groundwater ETI systems, as currently configured, and to examine
10 possible improvements to the configuration of the systems.

11 Greater resolution of hydrologic features was required to examine the groundwater
12 ETI systems at the level of detail required to evaluate the possible hydraulic effects of
13 water-disposal alternatives. Accordingly, additional discretization was used to refine the
14 finite-element mesh in the vicinity of some features (primarily percolation ponds) prior to
15 completing the predictive simulations. Values of hydraulic properties were not changed.

16 Predictive simulations were conducted using the forward and reverse particle tracking
17 capabilities of FEMWATER to simulate contaminant migration (Lin *et al.*, 1996).
18 Particle tracking does not incorporate contaminant concentrations or attenuation
19 mechanisms, but rather defines the path in three dimensions that a particle follows within
20 a particular groundwater flow field. Particle tracking thus is appropriate for use in
21 evaluating hydraulic containment and plume capture resulting from operation of
22 groundwater ETI systems.

23 The results of the plume-capture evaluation suggested that the groundwater ETI
24 systems at DDJC-Sharpe, in their current configuration, would not completely capture all
25 of the dissolved CAH in the North Balloon, Central Area, or South Balloon plumes. The
26 results of simulations also indicated that some extraction wells in the current systems are
27 redundant and/or ineffective as a consequence of their locations with respect to the
28 plumes. Additional simulations were then completed to assess the possible effects of
29 additional extraction wells in different locations.

1 At the conclusion of predictive simulations, WES noted potential limitations
2 associated with the numerical simulations, together with associated uncertainties in the
3 predicted results (USACE, 2000). In particular, WES expressed reservations regarding
4 hydrostratigraphic conceptualization, the values of hydraulic properties used in the
5 model, and the values assigned to model boundaries (in particular, head values assigned
6 to constant-head boundaries). Use of particle tracking to simulate contaminant migration
7 was also regarded as a limitation of the model, because particle-tracking techniques
8 generally do not incorporate attenuation mechanisms.

9 Parson agrees with the general approach taken by WES in developing the numerical
10 model. However, several issues require clarification, changes, or enhancements in order
11 to improve the capabilities of the model to simulate hydrogeologic conditions at DDJC-
12 Sharpe, thereby reducing the uncertainties in model predictions. Issues to be addressed
13 include the following:

- 14 1. The conceptual model developed by WES forms the framework upon which the
15 numerical model was constructed, and is a reasonable representation of
16 hydrogeologic conditions at DDJC-Sharpe. However, parts of the discussion of
17 the conceptual model should be re-stated to clarify that the groundwater system
18 at the facility comprises a single, heterogeneous, water-bearing unit, rather than
19 four separate and distinct “aquifers” (which is the impression given in the
20 discussion of the layers used in the numerical model).
- 21 2. The selection of model boundaries -- Louise Avenue to the south (only one mile
22 from the facility), Durham Ferry Road to the east (located only about 2,000 feet
23 east of the facility); Highway 5 to the west (located less than 2,000 feet from
24 the northwest corner of the site) and the northern boundary about 2,500 feet
25 north of the facility -- at short distances from DDJC-Sharpe may not be
26 appropriate for purposes of simulating hydrologic conditions on a regional
27 scale. None of the boundaries apparently was selected on the basis of
28 hydrologic conditions or features, which usually is desirable (c.f., Spitz and
29 Moreno, 1996). In addition, locating model boundaries at distances close to

hydrologic features of interest (e.g., groundwater extraction wells) can result in introduction of extraneous or misleading effects (“boundary effects”) in simulations, which are solely the result of the boundary. Boundary effects apparently were observed during transient simulations of groundwater extraction (USACE, 2000). In particular, the proximity of simulated extraction wells to model boundaries can adversely influence the results of pumping simulations and may not reflect actual drawdowns or hydraulic gradients.

3. In some circumstances, assigning specified head conditions to external boundaries of a model, and maintaining specified-head boundary conditions during steady-state and transient verifications, and subsequent simulations, can generate incorrect or misleading results. If the model domain is sufficiently small, or the hydraulic stresses applied within the model domain are of a magnitude sufficient to extend to a specified-head boundary, the boundary condition will affect all simulated hydraulic processes within the model domain. Specified-head boundaries also can mask or distort the response of the simulated groundwater system to hydraulic stresses (“pumping”) within the model domain, and are inappropriate for use in simulating seasonal changes in groundwater elevations or recharge. In the absence of a readily-apparent hydrologic feature or condition that reasonably could be simulated with specified-head or specified flux boundaries, the General Head Boundary (GHB) condition may have been a more reasonable boundary assignment.

4. The SSJID Canal also was simulated using a specified-head boundary during steady-state, transient, and predictive simulations. This may not be appropriate, because use of a specified-head boundary implies that water will be present in the canal year-round. In reality, groundwater-level and canal-stage data indicate that groundwater gradients and movement in the eastern part of DDJC-Sharpe, primarily in uppermost parts of the groundwater system, are influenced by water losses from the canal. During irrigation seasons when the canal contains water, the direction of groundwater movement in the eastern part of DDJC-Sharpe is primarily away from the canal, with a pronounced westerly

1 component. By contrast, when the canal is dry, the direction of groundwater
2 movement in the eastern part of the facility has a distinct northerly component.
3 A boundary condition corresponding to a specified rate of water loss from the
4 canal (Cauchy boundary condition) rather than a specified-head condition, may
5 have been more appropriate to simulate the hydrologic effects of the SSJID
6 Canal. Furthermore, use of a specified-head boundary condition to simulate the
7 canal probably influenced the predictive simulations of contaminant migration
8 and plume containment in hydrologically-unrealistic ways, because the
9 specified-head boundary condition controls the hydraulic gradients in that part
10 of the model domain.

- 11 5. Only a single value of horizontal hydraulic conductivity was assigned to each
12 model layer. This approach may not be representative of actual conditions, and
13 in particular does not account for phenomena such as preferential migration of
14 contaminants through more-permeable intervals (Section 2.3.2.2). A better
15 approach may have been to assign different values of hydraulic conductivity to
16 areas of the model as appropriate to simulate local variations in hydraulic
17 properties, or to generate a number of stochastic realizations of contaminant
18 migration, by randomly varying the spatial locations and extent to which
19 particular hydraulic properties were applied.

20 As a consequence of these concerns, Parsons regards the results of numerical model
21 simulations as uncertain and potentially misleading, and recommends that additional
22 numerical simulations should be considered only after the issues identified above have
23 been resolved.

24 **Evaluation of Hydraulic Containment and Contaminant Capture**

25 The characteristics of plume migration can be evaluated qualitatively by examining
26 changes in the areal distribution of contaminants through time, or by examining changes
27 in the concentrations of contaminants through time at individual well locations within or
28 downgradient from a plume. As discussed in Section 2.3.2.2, the extent of TCE in
29 groundwater in the third quarter of 1999 was compared with the extent of TCE in

1 groundwater in 1990, in order to examine the effects of attenuation processes and active
2 groundwater ETI, operating over a 10-year period, on the migration and persistence of
3 TCE in the subsurface. The TCE plume in the South Balloon and Central Area appears
4 to have decreased in areal extent during the period 1990 through the third quarter of
5 1999; and the apparent increase in extent of TCE in groundwater of the North Balloon
6 area between 1990 and the third quarter of 1999 appears to be an artifact of sampling, in
7 that groundwater samples were collected from nearly twice as many wells in 1999 as in
8 1990, thereby providing more information with which to better define the extent of TCE.
9 Therefore, the current groundwater extraction systems generally appear to be effective in
10 containing the plumes and limiting the further migration of TCE.

11 An individual extraction well (EW) is regarded as effective in limiting contaminant
12 migration if all of the following conditions are met:

- 13 • The well is located on a groundwater flowpath downgradient from areas within
14 which contaminants are present in groundwater at concentrations that are higher
15 than in areas downgradient from the well;
- 16 • The “capture zone” of the well (i.e., the area within which contaminants in
17 groundwater will be drawn toward the well as a consequence of pumping, rather
18 than past the well with ambient groundwater flow) is adequate to intercept
19 contaminants migrating in groundwater; and
- 20 • Contaminant concentrations in groundwater downgradient from the well decrease
21 or remain stable through time.

22 The location and radius of capture were evaluated for all extraction wells currently
23 operating as part of the North Balloon, Central Area, and South Balloon GWTPs at
24 DDJC-Sharpe, using the RESSQC module of USEPA’s Wellhead Protection Area
25 (WHPA) model (Blandford and Huyakorn, 1991). The capture zones of the complete
26 extraction systems also were examined using WHPA. WHPA is a screening-level
27 modular, semi-analytical groundwater flow model, designed to assist with wellhead
28 protection delineation programs. The WHPA model consists of four independent

1 computational modules (RESSQC, MWCAP, GPTRAC, and MONTEC) that may be
2 used to delineate capture zones. Input and output that were generated for various
3 simulations at DDJC-Sharpe are provided in Appendix D.

4 Analytical techniques for evaluating the capture zones of groundwater extraction wells
5 are relatively simplistic, and do not directly account for aquifer heterogeneities;
6 nevertheless, a screening-level assessment provides a means of evaluating the relative
7 effectiveness of a particular well or wellfield configuration, in restricting chemical
8 migration. The radius of capture for a particular extraction well depends on the well
9 pumping rate, the aquifer transmissivity, and the natural (steady-state) groundwater
10 hydraulic gradient and flow direction in the vicinity of the well. Capture-zone analyses
11 were completed for each of the three groundwater extraction systems at DDJC-Sharpe
12 (North Balloon, Central Area, and South Balloon). Because nearly all extraction wells at
13 DDJC-Sharpe are completed in discrete intervals of the water-bearing unit, with
14 relatively short screen lengths (generally 10 feet of screen; Table 4.6), extraction wells
15 produce water from vertically-separate parts of the water-bearing unit. Therefore,
16 simulations were completed for each separate monitoring zone (zones “A”, “B”, and
17 “C”), and the results then were superimposed, so that the capture zone of each system
18 could be evaluated through the full vertical extent of the water-bearing unit.

19 **“A” Monitoring Zone**

20 A range of transmissivity values was estimated for monitoring zone “A” (Section
21 2.2.3.5; Table 2.3) using the results of aquifer tests completed during the RI (ESE, 1990).
22 Three representative transmissivity values, within the range estimated for the “A” zone in
23 the North Balloon area (about 79 ft²/day, 300 ft²/day, and 890 ft²/day), were used in the
24 initial simulations. Because aquifer tests apparently have not been conducted in the “A”
25 zone at the South Balloon or in the Central Area, estimates of transmissivity in this part
26 of the groundwater system at DDJC-Sharpe were not available. Therefore, transmissivity
27 values in the upper range estimated for the North Balloon area (about 575 ft²/day, 675
28 ft²/day, and 975 ft²/day) were used for initial simulations of conditions in monitoring
29 zone “A” in the Central Area and the South Balloon. Hydraulic gradients and directions

1 of groundwater movement were estimated using potentiometric-surface maps (Figure 2.4)
2 generated from water-level data collected in the “A” monitoring zone in the third quarter
3 of 1999 (Radian, 1999g). The direction of groundwater movement in the “A” zone was
4 generally toward the northwest in 3Q99, with horizontal gradients of 0.00425 ft/ft,
5 0.00275 ft/ft, and 0.0025 ft/ft, in the North Balloon area, Central Area, and South Balloon
6 area, respectively (Table 4.14). This flow direction is judged to be representative of the
7 regional groundwater flow direction across DDJC-Sharpe prior to the initiation of
8 groundwater ETI activities (Section 2.2.3.4).

9 Three simulations (I, II, and III) initially were done for each “A”-zone extraction
10 system, using average extraction rates reported for 1999 for wells completed in the “A”
11 monitoring zone (Table 4.6), together with the selected transmissivity values (Table
12 4.14), to generate estimates of the capture zone that might result from pumping extraction
13 wells during the actual operational period for each groundwater ETI system. The
14 groundwater ETI system at the South Balloon has been in operation from 1987 to the
15 present; therefore, simulated operation of the South Balloon system through a 13-year
16 extraction period was used to evaluate the effects of the South Balloon system from 1987
17 through 1999. Similarly, a period of 5 years was used to simulate groundwater extraction
18 in the Central Area (where the system has been in operation since 1995); and a simulation
19 period of 10 years represented the operational history of the North Balloon groundwater
20 ETI system, from 1990 through 1999. These simulation periods were selected so that the
21 resulting capture zones could be compared with actual conditions reported for 3Q99. The
22 hydraulic effects associated with disposal of treated water in percolation ponds and
23 injection wells also were accounted for, using appropriate rates of injection/infiltration,
24 applied at well locations corresponding to injection wells and/or the centers of the
25 percolation ponds. The graphical results of these simulations are provided in Appendix D
26 (Figures D.1 through D.3), and present groundwater potentiometric contours, the
27 estimated 5- $\mu\text{g/L}$ isopleths for TCE in the “A” monitoring zone, and the extent of the
28 composite TCE plumes (which are projections of TCE concentrations in monitoring
29 zones “A”, “B” and “C” to a single datum). These results were compared with the
30 capture zone of each extraction system presented by Radian (1999g). Although the
31 reliability of the modeling approach used by WES in the FEMWATER model

TABLE 4.14
HYDRAULIC PARAMETERS USED IN CAPTURE-ZONE EVALUATIONS
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Simulation ^{a/}	Parameter	Area		
		North Balloon	Central Area	South Balloon
Monitoring Zone "A"				
I	Transmissivity (ft ² /day)	79	575	575
	Hydraulic Gradient (ft/ft)	0.00425	0.00275	0.0025
	Groundwater Flow Direction	Northwest	Northwest	Northwest
II	Transmissivity (ft ² /day)	300	675	675
	Hydraulic Gradient (ft/ft)	0.00425	0.00275	0.0025
	Flow Direction	Northwest	Northwest	Northwest
III	Transmissivity (ft ² /day)	890	975	975
	Hydraulic Gradient (ft/ft)	0.00425	0.00275	0.0025
	Groundwater Flow Direction	Northwest	Northwest	Northwest
Monitoring Zone "B"				
IV	Transmissivity (ft ² /day)	295	575	50
	Hydraulic Gradient (ft/ft)	0.00275	0.00225	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest
V	Transmissivity (ft ² /day)	295	1,520	425
	Hydraulic Gradient (ft/ft)	0.00275	0.00225	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest
VI	Transmissivity (ft ² /day)	300	2,700	800
	Hydraulic Gradient (ft/ft)	0.00275	0.00225	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest
Monitoring Zone "C"				
VII	Transmissivity (ft ² /day)	1,350	1,590	2,325
	Hydraulic Gradient (ft/ft)	0.002	0.0035	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest
VIII	Transmissivity (ft ² /day)	2,120	2,780	5,280
	Hydraulic Gradient (ft/ft)	0.002	0.0035	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest
IX	Transmissivity (ft ² /day)	3,470	3,460	8,810
	Hydraulic Gradient (ft/ft)	0.002	0.0035	0.002
	Groundwater Flow Direction	Northwest	Northwest	Northwest

^{a/} Graphic output displaying the results of simulations are presented in Appendix D.

(USACE, 2000) is uncertain (preceding section), it also was instructive to compare the results of the analytical capture-zone analysis with capture zones developed by WES (USACE, 2000).

Simulation I (Figure D.1), which utilized an “A”-zone transmissivity value of 79 ft²/day for the North Balloon area and 575 ft²/day for the South Balloon area (Table 4.14), was judged to replicate most nearly the conditions observed during 3Q99 in the “A” monitoring zone at the North Balloon and South Balloon. Simulation III (Figure D.3), which utilized a transmissivity value of 975 ft²/day for the Central Area, was judged to replicate most nearly the conditions observed during 3Q99 in the “A” monitoring zone at the Central Area. These capture zones encompass the TCE 5-μg/L isopleths, conform well with groundwater elevations in the “A” monitoring zone (as shown on Figures D.1 and D.3), and approximate the capture zones generated by WES (Figure D.4). For the purposes of capture-zone evaluations, transmissivity values of 79 ft²/day, 975 ft²/day, and 575 ft²/day, were considered to be representative of hydrogeologic conditions in the “A” monitoring zone at the North Balloon, Central Area, and South Balloon, respectively, and were used in subsequent simulations.

“B” Monitoring Zone

Representative transmissivity values for monitoring zone “B” also were selected from the range of transmissivity values estimated using the results of aquifer tests (Section 2.2.3.5; Table 2.3), and were used in simulating conditions in the “B” zone in the North Balloon, the Central Area, and the South Balloon (Table 4.14). The direction of groundwater movement and hydraulic gradients representative of conditions in the “B” monitoring zone were utilized in simulations of “B” zone groundwater extraction systems. Three simulations (Simulations IV, V, and VI) initially were done for each “B”-zone extraction system, using average extraction rates reported for 1999 for wells completed in the “B” monitoring zone (Table 4.6), together with the selected transmissivity values (Table 4.14), to generate estimates of the capture zone that might result from pumping extraction wells during the actual operational period for each groundwater ETI system. The graphical results of these simulations are provided in

Appendix D (Figures D.5 through D.7), and present groundwater potentiometric contours, the estimated 5- $\mu\text{g/L}$ isopleths for TCE in the “B” monitoring zone, and the extent of the composite TCE plumes. These results were compared with the capture zone of each extraction system presented by Radian (1999g), and with capture zones developed by WES using the FEMWATER model (USACE, 2000).

Simulation V (Figure D.6), which utilized a “B”-zone transmissivity value of about 295 ft^2/day for the North Balloon area, 1,520 ft^2/day for the Central Area, and 425 ft^2/day for the South Balloon area (Table 4.14), was judged to replicate most nearly the conditions observed during 3Q99 in the “B” monitoring zone at DDJC-Sharpe. These capture zones encompass the TCE 5- $\mu\text{g/L}$ isopleth, conform well with groundwater elevations in the “B” monitoring zone (as shown on Figure D.6), and approximate the capture zones generated by WES (Figure D.8). Therefore, transmissivity values of 295 ft^2/day , 1,520 ft^2/day , and 425 ft^2/day , were considered to be representative of hydrogeologic conditions in the “B” monitoring zone at the North Balloon, Central Area, and South Balloon, respectively, and were used in subsequent simulations.

“C” Monitoring Zone

Representative transmissivity values for monitoring zone “C” also were selected from the range of transmissivity values estimated using the results of aquifer tests (Section 2.2.3.5; Table 2.3), and were used in simulating conditions in the “C” zone in the North Balloon, the Central Area, and the South Balloon (Table 4.14). The direction of groundwater movement and hydraulic gradients representative of conditions in the “C” monitoring zone were utilized in simulations of “C” zone groundwater extraction systems. Three simulations (Simulations VII, VIII, and IX) initially were done for each “C”-zone extraction system, using average extraction rates reported for 1999 for wells completed in the “C” monitoring zone (Table 4.6), together with the selected transmissivity values (Table 4.14), to generate estimates of the capture zone that might result from pumping extraction wells during the actual operational period for each groundwater ETI system. The graphical results of these simulations are provided in Appendix D (Figures D.9 through D.11), and present groundwater potentiometric

1 contours, the estimated 5- μ g/L isopleths for TCE in the “C” monitoring zone, and the
2 extent of the composite TCE plumes. These results were compared with the capture zone
3 of each extraction system presented by Radian (1999g), and with capture zones
4 developed by WES using the FEMWATER model (USACE, 2000).

5 Simulation VII (Figure D.9), which utilized a “C”-zone transmissivity value of 1,350
6 ft²/day for the North Balloon area and 2,325 ft²/day for the South Balloon area (Table
7 4.14), was judged to replicate most nearly the conditions observed during 3Q99 in the
8 “C” monitoring zone at the North Balloon and South Balloon. Simulation VIII (Figure
9 D.10), which utilized a transmissivity value of 2,780 ft²/day for the Central Area, was
10 judged to replicate most nearly the conditions observed during 3Q99 in the “C”
11 monitoring zone at the Central Area. These capture zones encompass the TCE 5- μ g/L
12 isopleth, conform well with groundwater elevations in the “C” monitoring zone (as
13 shown on Figures D.9 and D.10), and approximate the capture zones generated by WES
14 (Figure D.12). Therefore, transmissivity values of 1,350 ft²/day, 2,325 ft²/day, and 2,780
15 ft²/day, were considered to be representative of hydrogeologic conditions in the “C”
16 monitoring zone at the North Balloon, Central Area, and South Balloon, respectively, and
17 were used in subsequent simulations.

18 **Optimization of Groundwater Extraction Systems**

19 After an appropriate transmissivity value had been selected for each monitoring zone
20 in the North Balloon area, Central Area, and South Balloon area, several additional
21 simulations were completed to evaluate whether the effectiveness of hydraulic
22 capture/containment of the extraction systems could be maintained with a smaller number
23 of extraction wells, and/or with different pumping rates. The extent of capture zones
24 associated with particular extraction wells in systems of different configurations are
25 indicated by dots of various colors on Figures D.1, D.2, D.3, D.5, D.6, D.7, D.9, D.10,
26 and D.11 (Appendix D). Using the results of these simulations, an optimized
27 containment system was developed for each depth interval (“monitoring zone”), and for
28 the full thickness of the water-bearing unit at DDJC-Sharpe.

1 The results of the assessment of hydraulic containment and contaminant capture in the
2 “A” monitoring zone indicate that wells EWA1, EWA3, EWA6, EWA7, EWA8, and
3 EWCA1, pumping at their 1999 average extraction rates, are as effective at maintaining
4 hydraulic capture in the South Balloon as are all nine currently-operational South Balloon
5 “A”-zone extraction wells pumping simultaneously (Figure 4.23 and Table 4.15). When
6 the percolation ponds in the Central Area are in active use, wells EWCAB1 and
7 EWCAB2 are not effective in achieving hydraulic containment of TCE (as defined by the
8 5 µg/L ACL isopleth) in the Central Area. Furthermore, inspection of groundwater
9 flowpaths into the capture zones of wells EWCAB1 and EWCAB2 (Appendix D)
10 indicates that for the most part, these wells are extracting clean water that has infiltrated
11 to “A”-zone groundwater from the percolation ponds. Alternative locations for “A”-zone
12 extraction wells in the Central Area were evaluated; however, all locations in the Central
13 Area appear to be influenced by infiltration from the percolation ponds, to the extent that
14 “A”-zone extraction wells could not effect hydraulic capture of the TCE µg/L ACL
15 isopleth. Therefore, Parsons recommends that currently-active “A”-zone wells EWCAB1
16 and EWCAB2 in the Central Area be removed from service (Table 4.15). Wells
17 EWNA2, EWNA4, EWNA6, and EWNA8, pumping at their 1999 average extraction
18 rates, are capable of effectively maintaining hydraulic capture in the North Balloon, even
19 though infiltration of treated water from the percolation ponds does affect groundwater
20 flowpaths and extraction-well capture zones in the North Balloon to a certain extent.

21 The results of the assessment of hydraulic containment and contaminant capture in the
22 “B” monitoring zone indicate that wells EWNB2, EWNB3, and EWNB6, operating at
23 their 1999 average extraction rates, are the only wells needed to effectively maintain
24 hydraulic capture in the “B” zone at the North Balloon area (Figure 4.24 and Table 4.15).
25 Wells EWCB1 and EWCB2 in the Central Area were relocated to the western boundary
26 of DDJC-Sharpe to improve contaminant capture at the leading edge of the TCE plume in
27 the “B” zone. Contaminant capture in the “B” zone in the western part of the Central
28 Area can be achieved even if treated water is re-injected in Central Area injection wells,
29 at cumulative rates as great as 75 gpm; however, inspection of groundwater flowpaths
30 into the capture zones of wells EWCB3 and EWCB4 (Appendix D) indicates that these

TABLE 4.15
OPTIMIZED GROUNDWATER EXTRACTION SYSTEM^{a/}
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Well	Monitoring Zone of Completion Interval	Approximate Screened Interval (ft bgs) ^{b/}	Design Production Rate (gpm) ^{c/}	Actual Production Discharge Rate (1999) (gpm)	Optimized Production Discharge Rate (gpm)
Extraction Wells in North Balloon Area					
EWNA1	A	30-40	10	3.3	Remove from service ^{d/}
EWNA2	A	55-65	30	11.9	11.9
EWNA3	A	40-50	20	23.6	Remove from service
EWNA4	A	35-45	30	15.7	15.7
EWNA5	A	35-45	10	1.6	Remove from service
EWNA6	A	27-37	10	9.0	9.0
EWNA7	A	48-58	10	Out of service ^{e/}	Remove from service
EWNA8	A	20-35	10	4.5	4.5
EWNA9	A	40-55	40	11.8	11.8
EWNA10	A	29-39	40	7.5	Remove from service
EWNB1	B	110-120	10	4.1	Remove from service
EWNB2	B	105-115	8	11.5	11.5
EWNB3	B	106-116	10	13.1	13.1
EWNB5	B	64-74	40	1.2	Remove from service
EWNB6	B	57.5-77.5	19	20.5	20.5
EWNC2R	C	75-95	40	37.3	37.3
EWNC3R	C	72-92	40	41.0	Remove from service
EWNC4R	C	87.8-97.8	40	40.1	40.1
Extraction Wells in Central Area					
EW CAB1	AB	28.1-33.1 & 44.7-49.7	40	12.8	Remove from service
EW CAB2	AB	29.6-49.8	30	11.4	Remove from service
EWCB2	B	81.8-91.8	30	50.5	50.5
EWCB3	B	55.3-59.7	30	23.5	Remove from service
EWCB4	B	82.1-91.9	30	48.1	Remove from service
EWCC1	C	135-144.9	60	81.6	81.6
EWCC2	C	98.3-108.3	30	51.7	51.7
EWCC3	C	128.1-137.9	60	91.4	91.4
EWCC4	C	100.8-110.8	60	109.5	109.5
Extraction Wells in South Balloon Area					
EWA1	A	20.7-30.7	10	2.1	2.1
EWA2	A	16-31.3	10	4.7	Remove from service
EWA3	A	15.4-30.8	10	1.4	1.4
EWA4	A	27-37.3	10	Out of service ^{f/}	Remove from service
EWA5	A	29.6-39.5	10	0.02	Remove from service
EWA6	A	20-30	10	3.2	3.2
EWA7	A	27-37	10	2.3	2.3
EWA8	A	20.1-35.5	10	7.3	7.3
EWA9	A	25.4-35.4	10	13.4	Remove from service
EWA10	A	25.4-35.4	10	5.1	Remove from service
EWCA1	A	30-40	50	4.3	4.3
EWB1	B	67.1-77.4	20	19.7	19.7
EWB2	B	44.5-55	20	2.0	Remove from service
EWB3	B	39-49.3	20	Out of service ^{g/}	Remove from service
EWCB1	B	48.8-58.8	50	12.1	12.1
EW C1	C	80.5-90.5	20	20.9	Remove from service
EW C2	C	91.5-102	20	36.6	Remove from service
EW C3	C	86-96	20	45.0	45.0

^{a/} Design details and well production rates for 1999 from Radian (1999g).
^{b/} ft bgs = feet below ground surface.
^{c/} gpm = gallons per minute.
^{d/} "Remove from service " indicates that the well should not be operational in an optimized groundwater extraction/injection system.
^{e/} Well EWNA7 was removed from service in the 4th quarter of 1997.
^{f/} Well EWA4 was removed from service in 1999.
^{g/} Well EWB3 was not in service in 1999.

- 1 **Figure 4.23 Results of Simulations to Optimize Contaminant Capture in the “A”**
- 2 **Zone**
- 3

- 1 **Figure 4.24 Results of Simulations to Optimize Contaminant Capture in the “B”**
- 2 **Zone**
- 3

1 wells probably are extracting clean water that has been discharged by “B”-zone injection
2 wells, and are generally ineffective. Therefore, Parsons recommends that currently-
3 active “B”-zone wells EWCB3 and EWCB4 in the Central Area be removed from service
4 (Table 4.15). Only a single well (well EWB1), operating at its 1999 average extraction
5 rate, is needed to maintain hydraulic capture in the “B” zone at the South Balloon area
6 (Figure 4.24 and Table 4.15).

7 The results of the assessment of hydraulic containment and contaminant capture in the
8 “C” monitoring zone indicate that wells EWNC2R and EWNC4R, operating at their 1999
9 average extraction rates, are the only wells needed to effectively maintain hydraulic
10 capture in the “C” zone at the North Balloon area; and well EWC3, if relocated
11 approximately 800 feet downgradient (west) of its current location, and operating at its
12 1999 average extraction rate, is capable of maintaining hydraulic capture in the “C” zone
13 at the South Balloon area (Figure 4.25 and Table 4.15). The “C”-zone groundwater
14 extraction system in the Central Area appears to be optimized in its current configuration,
15 and no changes were made to the Central Area system.

16 After the groundwater extraction systems in the “A”, “B”, and “C” monitoring zones
17 had been optimized, capture zones for each extraction system and monitoring zone were
18 superimposed and posted on Figure 4.26, together with the 1999 composite TCE plume.
19 Comparison of the superimposed capture zones of the optimized systems (Figure 4.26)
20 with the capture zones of the groundwater extraction systems, as currently (1999)
21 configured and operated (Figure 4.27), indicates that the optimized extraction systems are
22 capable of hydraulically containing the 1999 composite TCE plume as effectively as the
23 current extraction systems, even though the optimized systems include 18 fewer
24 operating wells than the systems in their current configuration, and extract groundwater
25 at a lower total rate (about 660 gpm as compared with the current total extraction rate of
26 about 920 gpm; Table 4.15).

27 If the annual O&M cost per well is approximately \$10,700 (in current dollars; Section
28 4.2.1.5), removing 18 of the currently-active wells from service could generate annual

1

2 **Figure 4.25 Results of Simulations to Optimize Contaminant Capture in the “C”**
3 **Zone**

4

- 1 **Figure 4.26 Optimized Composite (“A”, “B”, and “C” Zones) Groundwater**
- 2 **Extraction Wellfield**
- 3

- 1 **Figure 4.27 Current Composite (“A”, “B”, and “C” Zones) Groundwater**
- 2 **Extraction Wellfield**
- 3

O&M costs savings on the order of \$193,000, as a result of reductions in labor, utility, and analytical costs associated with system O&M.

4.2.3 Evaluation of Groundwater Treatment System

At each of the GWTPs at DDJC-Sharpe, extracted groundwater is treated by passing it through twin air-stripping towers in series (essentially, the water is treated twice) to remove volatile COCs (primarily TCE) prior to discharge to the SSJIDC, the percolation ponds, the re-injection wells, or the Dynegy® line (Figures 4.10 and 4.11). The results of analyses of water samples collected from the influent and effluent lines of the treatment plants (Radian, 1999g; *ibid.*, 2000c) indicate that the concentrations of TCE in influent water, collected from sampling ports in the influent lines upstream of the treatment plants, generally are less than about 40 µg/L -- in August 2000, the influent concentration of TCE to the North Balloon GWTP was 17 µg/L; the influent concentration of TCE to the Central Area “A” treatment train was 33 µg/L; the influent concentration of TCE to the Central Area “B”/”C” treatment train was 21 µg/L; and the influent concentration of TCE to the South Balloon GWTP was 38 µg/L. The concentrations of TCE in treated effluent invariably are below the detection limit (0.5 µg/L). This indicates that the treatment plant is effective in meeting the effluent treatment standards required by the ROD for OU1 (Section 3.1.4).

However, the low influent concentrations of TCE suggest that treatment of extracted groundwater by passing the water through two stripping towers in series may not be necessary. During the sampling event of July – August 2000, Parsons personnel collected water samples from the influent lines to the GWTPs in the “B”/”C” treatment train in the Central Area, and in the South Balloon. Water samples were also collected from the lines between the two stripping towers at each GWTP. This second set of samples was collected to evaluate the concentrations of VOCs in water after it had been treated by passing through a single stripping tower, but before it had been treated in the second of the two towers. Water samples were collected in 40-mL volatile organics analysis (VOA) vials, in accordance with the provisions of the SAP for collection of field data, and submitted to CALTest Laboratories, Inc., of Napa, California, for analysis of VOCs. Water samples were not collected from the North Balloon GWTP.

1 TCE was detected in the water sample from the influent line to the Central Area
2 “B”/”C” GWTP, at a concentration of 22 µg/L; and *cis*-1,2-DCE and TCE were detected
3 in the water sample from the influent line to the South Balloon GWTP, at concentrations
4 of 4.2 µg/L and 36 µg/L, respectively (Table 4.16). TCE was not detected in the water
5 sample from the line between the stripping towers at the Central Area “B”/”C” GWTP.
6 *cis*-1,2-DCE was not detected in the water sample from the line between the stripping
7 towers at the South Balloon area GWTP; and TCE was detected, at a concentration of 0.9
8 µg/L (slightly greater than the discharge standard for TCE) in the same water sample
9 from the South Balloon GWTP.

10 It therefore seems likely that a single air-stripping tower, rather than twin air-stripping
11 towers, may be sufficient for treatment of extracted groundwater at the Central Area
12 “B”/”C” GWTP. The concentrations of VOCs in extracted groundwater influent to the
13 North Balloon GWTP (which was not sampled) historically have been the lowest among
14 the influent concentrations. Therefore, it is possible that a single air-stripping tower at
15 the North Balloon GWTP also would be sufficient to treat groundwater extracted from
16 the North Balloon area. Currently, treatment of extracted groundwater influent to the
17 Central Area “A” GWTP and the South Balloon GWTP, using a single air-stripping
18 tower at each GWTP, is unlikely to achieve effluent treatment standards required by the
19 ROD for OU1. If the GWTP air-stripping circuits at the North Balloon GWTP and the
20 Central Area “B”/”C” GWTP could be re-routed inexpensively to bypass the second
21 tower in each circuit, long-term OM&M costs associated with operating two air-stripping
22 towers could be reduced or eliminated. However, potential cost savings associated with
23 this modification are difficult to quantify.

24 **4.2.4 Summary of Results of Groundwater ETI System Evaluation**

25 Based on the results of the RPO evaluation, the future focus of active groundwater
26 remediation efforts at DDJC-Sharpe should be hydraulic containment of the plume using
27 the minimum number of wells necessary to effect plume capture. Removal of
28 contaminant mass in groundwater at DDJC-Sharpe should not be a priority for future
29 operation of the groundwater ETI systems because evaluation of the systems suggests

TABLE 4.16
COCs^{a/} DETECTED IN EXTRACTED GROUNDWATER
JULY - AUGUST 2000
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Sample Location	Sampling Date	cis-1,2-DCE ^{b/} (µg/L) ^{d/}	TCE ^{c/} (µg/L)
Influent line to Central Area "B" / "C" treatment plant	07/25/00	< 0.1 ^{e/}	22
Between stripping towers at Central Area "B" / "C" treatment plant	07/25/00	< 0.1	< 0.3
Influent line to South Balloon treatment plant	07/25/00	4.2	36
Between stripping towers at South Balloon treatment plant	07/25/00	< 0.1	0.9

^{a/} COCs = constituents of concern identified in the Record of Decision for OU1 (ESE, 1993a).

^{b/} cis-1,2-DCE = cis-1,2-dichloroethene

^{c/} TCE = trichloroethene

^{d/} µg/L = micrograms per liter.

^{e/} "<" indicates that the concentration was less than the reported detection limit.

1 that they are relatively ineffective at mass removal. On the other hand, the assessment of
2 natural-attenuation potential at DDJC-Sharpe (Section 2.3.3) indicates that
3 biodegradation processes are destroying CAH mass in the subsurface at appreciable rates.
4 Most of the extraction wells recommended for removal from operation on the basis of the
5 capture-zone optimization are also marginal or ineffective at removal of contaminant
6 mass (compare Tables 4.11, 4.12, and 4.13 with Table 4.15). If the current groundwater
7 ETI systems are modified to optimize containment and capture of contaminants, the
8 relatively ineffective mass-removal capabilities of the extraction systems will be
9 supplemented by natural-attenuation processes.

10 Examination of the cumulative mass removal through time by the Central Area “A”-
11 zone GWTP (Section 4.2.2.1; Figure 4.12) indicates that TCE mass-removal rates at this
12 GWTP have become asymptotic, suggesting that little additional TCE mass can be
13 removed by continued operation of this system. Evaluation of hydraulic containment and
14 contaminant capture in the Central Area (Section 4.2.2.2) indicates that the “A”-zone
15 extraction wells in the Central Area could probably be removed from service. Currently,
16 groundwater from the “A” zone in the Central Area is managed and disposed separately
17 from groundwater extracted from the “B” and “C” zones, as a consequence of elevated
18 levels of arsenic in groundwater extracted from wells completed in the “A” monitoring
19 zone. If “A”-zone extraction wells in the Central Area could be removed from service,
20 the Central Area “A”-zone treatment train could be taken off-line, and arsenic in disposed
21 water would no longer be an issue. This improvement could also generate efficiencies
22 and cost savings, although the potential range of savings is difficult to quantify.

23 **4.3 EVALUATION OF GROUNDWATER MONITORING PROGRAM**

24 Groundwater monitoring programs have two primary objectives (USEPA, 1992;
25 Gibbons, 1994):

- 26 1. Evaluate long-term temporal trends in contaminant concentrations at one or
27 more points within or outside of the remediation zone, as a means of
28 monitoring the performance of the remedial measure(s) being implemented
29 (*temporal evaluation*); and

2. Evaluate the extent to which contaminant migration is occurring, particularly if a potential exposure point for a susceptible receptor exists (*spatial evaluation*).

The relative success of any remediation system and its components (including the monitoring network) must be judged based on its ability to achieve the stated objectives of the system. Designing an effective groundwater monitoring program involves locating monitoring points and developing a site-specific strategy for groundwater sampling and analysis so as to maximize the amount of relevant information that can be obtained while minimizing incremental costs. Relevant information is that required to effectively address the temporal and spatial objectives of monitoring. The effectiveness of a monitoring network in achieving these two primary objectives can be evaluated quantitatively using statistical techniques. In addition, there may be other important considerations associated with a particular monitoring network that are most appropriately addressed through a qualitative hydrogeologic evaluation of the network. The qualitative evaluation may consider such factors as hydrostratigraphy, locations of potential receptors with respect to a dissolved-contaminant plume, and the direction(s) and rate(s) of contaminant migration. The evaluation of a monitoring network is therefore conducted in stages to address each of the objectives and considerations of monitoring: a qualitative evaluation is first completed, followed in succession by temporal and spatial evaluations. The procedures for evaluating a monitoring program are demonstrated in the following subsections, for the current program (proposed by Radian [1999g]) at the South Balloon area. The procedures used could be applied generally to all of DDJC-Sharpe, or to other areas on the facility.

4.3.1 Qualitative Hydrogeologic Evaluation of South Balloon Monitoring Program

An effective monitoring program will provide information regarding plume migration and changes in chemical concentrations through time at appropriate locations, enabling decision-makers to verify that contaminants are not endangering potential receptors, and that remediation is occurring at rates sufficient to achieve RAOs. The design of the monitoring program should therefore include consideration of existing receptor exposure pathways, as well as exposure pathways arising from potential future use of the groundwater.

1 Performance monitoring wells located upgradient, within, and just downgradient from
2 a plume provide a means of evaluating system effectiveness with respect to performance
3 criteria. Long-term monitoring (LTM) of these wells also provides information about
4 migration of the plume and temporal trends in chemical concentrations. Contingency
5 monitoring wells downgradient from the plume are used to ensure that the plume is not
6 expanding past the remediation zone or containment system, and to trigger a contingency
7 remedy if contaminants are detected. Primary factors to consider include at a minimum:

- 8 • Types of contaminants,
- 9 • Aquifer heterogeneity,
- 10 • Distance to potential receptor exposure points,
- 11 • Groundwater seepage velocity,
- 12 • Potential surface-water impacts, and
- 13 • The effects of the remediation system.

14 These factors will influence the locations and spacing of monitoring points and the
15 sampling frequency. Typically, the greater the seepage velocity and the shorter the
16 distance to receptor exposure points, the more frequently groundwater sampling should
17 be conducted. One of the most important purposes of LTM is to confirm that the
18 contaminant plume is behaving as predicted. Visual and statistical tests of chemical
19 concentration data collected through time can be used to evaluate plume stability. If a
20 groundwater remediation system is effective, then over the long term, groundwater
21 monitoring data should demonstrate a clear and meaningful decreasing trend in
22 concentrations at appropriate monitoring points.

23 Monitoring is conducted periodically at DDJC Sharpe to provide information
24 regarding chemical and hydraulic (gradient) conditions within and downgradient from the
25 contaminant plumes at DDJC-Sharpe (Radian, 1999g). The groundwater monitoring
26 program is intended to provide water-level and analytical data for use in ensuring
27 compliance with requirements of the ROD (Radian, 1999g), and for evaluating the

1 overall effectiveness of the extraction system. The components of the groundwater
2 monitoring program include:

3 • **Compliance monitoring.** This component of the monitoring program is used to
4 assess periodically the quality of groundwater quality in the various monitoring
5 zones of the water-bearing unit, in order to evaluate whether cleanup criteria are
6 being/have been achieved and maintained.

7 • **Water-level monitoring.** This component of the monitoring program is used to
8 evaluate whether the groundwater contaminant plume is hydraulically contained
9 by the groundwater extraction system.

10 • **Treatment-system performance monitoring.** The purpose of this component of
11 the monitoring program is to assess performance of the treatment systems and to
12 monitor the quality of the water exiting the treatment system for discharge to the
13 SSJIDC, infiltration via the percolation ponds, aquifer re-injection, or other
14 method of disposal.

15 Currently (2000) (based on proposed monitoring plan presented in Radian, 1999g),
16 groundwater samples are collected periodically (quarterly, semi-annually, annually, or
17 biennially) for monitoring purposes, using conventional-purge and low-flow purge
18 sampling methods, from 48 monitoring wells and 4 inactive production wells at the South
19 Balloon area, and analyzed for VOCs using USEPA Method SW8021 (Table 4.17).
20 Groundwater samples also are collected from various wells and analyzed for other
21 parameters including BTEX and fuel hydrocarbons (using USEPA Method SW8015),
22 SVOCs (using USEPA Method 8270C), bromacil (using USEPA Method E507), nitrate
23 (using USEPA Method E300.0), and various metals (using USEPA Methods SW6010
24 and SW7196) (Table 4.17). In addition to collection of samples from monitoring wells,
25 key components of the groundwater extraction and treatment system at the South Balloon
26 area also are monitored, enabling overall system performance to be evaluated
27 periodically. Monitoring of the extraction and treatment system may include collection
28 of groundwater samples from the effluent discharge lines of 15 active extraction wells, so
29 that the removal of contaminant mass from the subsurface through time can be evaluated.

TABLE 4.17
CURRENT GROUNDWATER MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
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Monitoring Point	Laboratory Analyses (Frequency)										
	VOCs ^{b/} (Method SW8021)	BTEX ^{c/} (Method SW8015)	SVOCs ^{d/} (Method SW8270/8270C)	TPH ^{d/} (Method SW8015)	Bromacil (Method E507)	Arsenic (Method SW6010/6010B)	Total Chromium (Method SW6010/6010B)	Hexavalent Chromium (Method SW7196)	Lead (Method SW6010/6010B)	Selenium (Method SW6010/6010B)	Nitrate (Method E300.0)
Extraction and Monitoring Wells in Monitoring Zone "A"											
EWA1	Quarterly										
EWA2	Quarterly										
EWA3	Quarterly										
EWA4	Quarterly										
EWA5	Quarterly										
EWA6	Quarterly										
EWA7	Quarterly					Annual	Annual		Annual		
EWA8	Quarterly					Annual	Annual		Annual		
EWA9	Quarterly					Annual	Annual		Annual		
EWA10	Quarterly					Annual	Annual		Annual		
MW401A						Annual	Annual		Annual		
MW402A						Semi-Annual	Semi-Annual	Semi-Annual	Semi-Annual		
MW403A						Semi-Annual	Annual		Annual		
MW406A	Biennial					Semi-Annual	Semi-Annual	Annual	Semi-Annual		
MW407A	Biennial				Annual	Semi-Annual					
MW415A	Quarterly										
MW417A	Biennial				Annual						
MW418AR	Biennial			Biennial		Annual	Annual	Annual	Annual		
MW422A	Biennial										
MW424A						Semi-Annual	Semi-Annual	Annual	Semi-Annual		
MW425A	Biennial					Annual	Annual		Annual		
MW427A	Biennial										
MW440A	Biennial					Annual	Annual		Annual		
MW441A	Biennial					Annual	Annual		Annual		
MW445A	Quarterly										
MW473A	Biennial		Biennial	Annual		Annual	Annual	Annual	Annual		
MW475A	Biennial										
MW476A	Biennial	Annual	Biennial	Annual		Biennial	Biennial		Biennial		
MW489A						Annual	Annual		Annual		
MW503A	Biennial										
MW508A	Annual				Annual						
MW523A	Quarterly										
MW523AB	Quarterly										
MW524A	Quarterly										
DW001	Biennial										
DW002	Biennial					Semi-Annual	Semi-Annual	Semi-Annual	Semi-Annual		
DW003	Annual					Semi-Annual	Semi-Annual		Semi-Annual		
DW004	Biennial					Semi-Annual	Semi-Annual	Annual	Semi-Annual		
Extraction and Monitoring Wells in Monitoring Zone "B"											
EWB1	Quarterly					Annual	Annual		Annual		
EWB2	Quarterly										
MW402B	Biennial										
MW407B	Biennial				Biennial						
MW418B	Annual										
MW422B	Biennial										
MW427B	Biennial										
MW433B	Annual										
MW434B						Annual	Annual		Annual		
MW440B	Biennial					Annual	Annual		Annual		
MW441B	Biennial					Annual	Annual		Annual		
MW445B	Quarterly										
MW448B	Annual										
MW503B	Biennial										
MW508B	Annual				Biennial						
MW523B	Quarterly										
Extraction and Monitoring Wells in Monitoring Zone "C"											
EW C1	Quarterly										
EW C2	Quarterly										
EW C3	Quarterly										
MW402C	Biennial										
MW407C	Quarterly					Semi-Annual	Semi-Annual		Semi-Annual		
MW418C	Annual										
MW427C	Biennial										
MW440C	Biennial					Annual	Annual		Annual		
MW441C	Biennial										
MW445C	Quarterly										
MW449C	Biennial										
MW450C	Biennial										
MW503C	Semi-Annual										
MW508C	Quarterly										
Monitoring Wells in Monitoring Zone "D"											
MW402CD	Biennial										
MW451CD	Biennial										
MW524CD	Quarterly										

TABLE 4.17 (Continued)
CURRENT GROUNDWATER MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
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Monitoring Point	Laboratory Analyses (Frequency)										
	VOCs ^{b/} (Method SW8021)	BTEX ^{c/} (Method SW8015)	SVOCs ^{d/} (Method SW8270/8270C)	TPH ^{e/} (Method SW8015)	Bromacil (Method E507)	Arsenic (Method SW6010/6010B)	Total Chromium (Method SW6010/6010B)	Hexavalent Chromium (Method SW7196)	Lead (Method SW6010/6010B)	Selenium (Method SW6010/6010B)	Nitrate (Method E300.0)
MW401D	Biennial	Annual		Annual							
MW402D	Biennial										
South Balloon Treatment Plant											
Influent line	Bi-Weekly										
Effluent line	Bi-Weekly				Monthly	Weekly ^{f/}				Monthly	Monthly

^{a/} Groundwater monitoring program proposed for 2000 by Radian (1999g).

^{b/} VOCs = volatile organic compounds.

^{c/} BTEX = benzene, toluene, ethylbenzene, and xylene isomers.

^{d/} SVOCs = semi volatile organic compounds.

^{e/} TPH = total petroluem hydrocarbons.

^{f/} Suite of 23 analytes using trace ICPES; mercury analyzed using USEPA Method SW7470; arsenic analyzed using USEPA Method SW7060 (Radian, 1999g).

1 Samples of extracted groundwater may be collected from any of four sampling ports
2 within the system during weekly, bi-weekly or monthly monitoring events (Table 4.17);
3 those samples are analyzed for VOCs, metals, pesticides, PCBs, and nitrate.

4 The estimated annual costs associated with the current groundwater monitoring
5 program at the South Balloon area are summarized in Table 4.18. As a consequence of
6 the absence of a discernible trend in TCE concentrations in groundwater samples from 10
7 of the extraction wells in the South Balloon area, it is not possible to estimate the length
8 of time that will be required to meet the ACL concentration cleanup objective specified in
9 the ROD for OU1 (Section 3.1.2.1). Based on the projected trend in TCE concentrations
10 for well EWCB1 in the South Balloon, it is possible that cleanup objectives for
11 groundwater in the South Balloon may be achieved no earlier than 2074 (a period of
12 approximately 75 years). For the purpose of generating cost estimates, Parsons assumed
13 that an additional 75-year period will be required to achieve the cleanup objectives
14 specified in the ROD. Assuming that the current monitoring program is continued for an
15 additional 75 years, the cumulative cost of the monitoring program (in constant 2000
16 dollars) is estimated to be approximately \$18,700,000 (Table 4.18).

17 The direction of groundwater movement beneath DDJC Sharpe has historically been
18 from southeast to west or northwest (Section 2.2.3.4). Therefore, in the absence of active
19 groundwater extraction, migration of contaminants from sources in the South Balloon
20 area also would be generally toward the northwest, and contaminants dissolved in
21 groundwater at the South Balloon area will continue to migrate to the northwest. The
22 leading edge of the dissolved CAH plume originating in the South Balloon area is several
23 hundred feet beyond the western boundary of DDJC-Sharpe (Figure 2.13). Evaluation of
24 the extent of COCs in groundwater (Section 2.3.2) and the potential for natural
25 attenuation of CAH in groundwater at DDJC-Sharpe (Section 2.3.3) suggests that the
26 maximum concentrations of TCE in much of the groundwater system downgradient of
27 the North Balloon, Central Area, and South Balloon area are near or below MCLs and
28 may be declining due to natural attenuation rather than active groundwater extraction.
29 Although dissolved TCE in groundwater originating at the North Balloon, Central Area,
30 and South Balloon area has migrated beyond the western boundary of DDJC-Sharpe,

TABLE 4.18
ESTIMATED COSTS ASSOCIATED WITH CURRENT MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
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26 Wells Sampled Quarterly					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	52	hours	\$ 65.00	\$	3,380.00
Labor for data validation and data management					
1 person at \$65/hr	52	hours	\$ 65.00	\$	3,380.00
Reporting					
260 hours at \$80/hr	260	hours	\$ 80.00	\$	20,800.00
Laboratory Analyses					
VOCs ^{b/} by Method 8021B (primary samples + QA/QC)	30	samples	\$ 155.00	\$	4,650.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.) ^{d/}	7	days	\$ 400.00	\$	2,600.00
Vehicle Rental (1 vehicle for 1 day)	7	days	\$ 55.00	\$	357.50
Miscellaneous Field Supplies				\$	100.00
SUBTOTAL QUARTERLY COSTS				\$	35,267.50
8 Wells Sampled Semi-Annually					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	16	hours	\$ 65.00	\$	1,040.00
Labor for data validation and data management					
1 person at \$65/hr	16	hours	\$ 65.00	\$	1,040.00
Reporting					
80 hours at \$80/hr	80	hours	\$ 80.00	\$	6,400.00
Laboratory Analyses					
VOCs by Method SW8021B (primary samples + QA/QC)	3	samples	\$ 155.00	\$	465.00
Metals ^{d/} by Method SW6010/6010B (primary samples +QA/QC)	11	samples	\$ 75.00	\$	825.00
Hex chromium ^{e/} by Method SW7196 (primary samples +QA/QC)	4	samples	\$ 45.00	\$	180.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	2	days	\$ 400.00	\$	800.00
Vehicle Rental (1 vehicle for 1 day)	2	days	\$ 55.00	\$	110.00
Miscellaneous Field Supplies				\$	100.00
SUBTOTAL SEMI-ANNUAL COSTS				\$	10,960.00

TABLE 4.18 (Continued)
ESTIMATED COSTS ASSOCIATED WITH CURRENT MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
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18 Wells Sampled Annually					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	36	hours	\$ 65.00	\$	2,340.00
Labor for data validation and data management					
1 person at \$65/hr	36	hours	\$ 65.00	\$	2,340.00
Reporting					
180 hours at \$80/hr	180	hours	\$ 80.00	\$	14,400.00
Laboratory Analyses					
VOCs by Method SW8021B (primary samples + QA/QC)	10	samples	\$ 155.00	\$	1,550.00
Metals by Method SW6010/6010B (primary samples +QA/QC)	18	samples	\$ 75.00	\$	1,350.00
Hex chromium by Method SW7196 (primary samples +QA/QC)	7	samples	\$ 45.00	\$	315.00
BTEX/TPH ^{f/} by Method SW8015 (primary samples + QA/QC)	5	samples	\$ 75.00	\$	375.00
Bromacil by Method E507 (primary samples + QA/QC)	6	samples	\$ 142.00	\$	852.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	5	days	\$ 400.00	\$	1,800.00
Vehicle Rental (1 vehicle for 1 day)	5	days	\$ 55.00	\$	247.50
Miscellaneous Field Supplies				\$	100.00
SUBTOTAL ANNUAL COSTS				\$	25,669.50
17 Wells Sampled Biennially					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	34	hours	\$ 65.00	\$	2,210.00
Labor for data validation and data management					
1 person at \$65/hr	34	hours	\$ 65.00	\$	2,210.00
Reporting					
170 hours at \$80/hr	170	hours	\$ 80.00	\$	13,600.00
Laboratory Analyses					
VOCs by Method SW8021B (primary samples + QA/QC)	21	samples	\$ 155.00	\$	3,255.00
SVOCs by Method SW8270/8270C (primary samples + QA/QC)	4	samples	\$ 260.00	\$	1,040.00
Metals by Method SW6010/6010B (primary samples +QA/QC)	3	samples	\$ 75.00	\$	225.00
BTEX/TPH ^{e/} by Method SW8015 (primary samples + QA/QC)	3	samples	\$ 75.00	\$	225.00
Bromacil by Method E507 (primary samples + QA/QC)	4	samples	\$ 142.00	\$	568.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	4	days	\$ 400.00	\$	1,600.00
Vehicle Rental (1 vehicle for 1 day)	4	days	\$ 55.00	\$	220.00
Miscellaneous Field Supplies				\$	-
SUBTOTAL BIENNIAL COSTS				\$	25,153.00

TABLE 4.18 (Continued)
ESTIMATED COSTS ASSOCIATED WITH CURRENT MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
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Monthly Treatment Plant Influent/Effluent Sampling					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	8	hours	\$	65.00	\$ 520.00
Labor for data validation and data management					
1 person at \$65/hr	8	hours	\$	65.00	\$ 520.00
Reporting					
10 hours at \$80/hr	10	hours	\$	80.00	\$ 800.00
Laboratory Analyses					
VOCs by Method SW8021B (primary samples + QA/QC)	6	samples	\$	155.00	\$ 930.00
Selenium by Method SW7740 (primary sample +QA/QC)	3	samples	\$	30.00	\$ 90.00
Arsenic by Method 7060 (primary sample +QA/QC)	3	samples	\$	30.00	\$ 90.00
Bromacil by Method E507 (primary samples + QA/QC)	3	samples	\$	142.00	\$ 426.00
Nitrates by Method E300.0 (primary samples + QA/QC)	3	samples	\$	25.00	\$ 75.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	1	day	\$	400.00	\$ 400.00
Vehicle Rental (1 vehicle for 1 day)	1	day	\$	55.00	\$ 55.00
Miscellaneous Field Supplies					\$ 50.00
				SUBTOTAL MONTHLY COSTS	\$ 3,956.00
				TOTAL ANNUAL COSTS	\$ 248,708.00

Long Term Monitoring for 75 years:
TOTAL MONITORING PROGRAM COST -- SOUTH BALLOON AREA \$18,653,100.00

^{a/} Estimated by Parsons based on sampling program proposed for 2000 by Radian (1999g) (Table 4.17).

^{b/} VOCs = volatile organic compounds.

^{c/} PID = photo ionization detector.

^{d/} Metals analyses include arsenic, chromium, and lead.

^{e/} Hex Chrome = hexavalent chromium.

^{f/} Benzene, toluene, ethylbenzene, and xylene isomers (BTEX) are reported as part of the TPH analyses performed by Radian Analytical Services.

1 given the occurrence and rates of natural attenuation processes in the subsurface, it is
2 possible that even in the absence of active groundwater extraction, TCE will not migrate
3 in groundwater to the nearest identified point of potential human exposure (the potable
4 water wells, located more than 1,500 feet west of DDJC-Sharpe) at concentrations of
5 potential concern.

6 Several monitoring wells are located at great distances (hundreds to thousands of feet)
7 downgradient from the dissolved CAH plumes emanating from the South Balloon area.
8 For example, monitoring well MW508A is about 1,000 feet downgradient from the distal
9 (leading) edge of the South Balloon CAH plume, and well MW503A is about 2,500 feet
10 downgradient (Figure 2.13). If TCE were to move as a conservative constituent (i.e., if
11 TCE were not retarded during migration; Appendix B), at the average linear velocity of
12 groundwater (about 0.14 ft/day, or 50 ft/year; Section 2.2.3.5), and if natural attenuation
13 processes (sorption, dispersion, volatilization, degradation; Appendix B) did not cause
14 TCE concentrations to decrease to levels below detection limits as migration proceeded, a
15 period of about 20 years would be required for TCE to migrate from the leading edge of
16 the South Balloon CAH plume to well MW508A; and a period of about 50 years would
17 be required for TCE to migrate from the leading edge of the South Balloon CAH plume
18 to well MW508A.

19 In any situation (no extraction, limited groundwater extraction, or active groundwater
20 extraction and treatment) virtually all contaminant mass in groundwater at DDJC-Sharpe
21 will remain in close proximity to the facility in the short term. This suggests that
22 although periodic monitoring of groundwater conditions should be continued to address
23 the two objectives of monitoring listed above, the frequency of monitoring at most
24 locations could be reduced from quarterly and semi-annually to annual and biennial
25 monitoring (Table 4.19), while some wells could be abandoned completely, with little
26 loss of information and no increase in risk to potential receptors.

27 Examination of the list of groundwater monitoring wells included in the periodic
28 monitoring program suggests that some sampling points may be redundant or
29 unnecessary. For example, groundwater samples are collected from monitoring wells

TABLE 4.19
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING PROGRAM
SOUTH BALLOON AREA
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Monitoring Point	Sampling for VOCs ^{a/} /SVOCs ^{b/}			Rationale for VOC/SVOC Sampling to be Retained or Abandoned	Sampling for Other Constituents ^{c/}				Rationale for Sampling for Other Constituents to be Retained or Abandoned
	Abandon/Retain?		Sampling Frequency		Abandon/Retain?		Constituent	Sampling Frequency	
	Abandon	Retain			Abandon	Retain			
Extraction and Monitoring Wells in Monitoring Zone "A"									
EWA1		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA2		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA3		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA4		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA5		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA6		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWA7		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
EWA8		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
EWA9		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
EWA10		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
MW401A	✓			Not currently sampled		✓	Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
MW402A	✓			Not currently sampled		✓	Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
MW403A	✓			Not currently sampled		✓	As	Annual	Monitor concentrations of arsenic in area where arsenic in groundwater exceeds background concentrationsd/
MW406A		✓	Biennial	Currently non-detect; monitor plume migration downgradient of source area		✓	Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
MW407A		✓	Biennial	TCE concentrations currently decreasing; monitor downgradient plume migration		✓	As	Annual	Monitor concentrations of arsenic in area where arsenic in groundwater exceeds background concentrations
MW415A		✓	Biennial	TCE concentrations below ACL and currently decreasing; monitor downgradient plume migration	✓				Not currently sampled
MW417A		✓	Biennial	TCE concentrations have decreased to non-detect; monitor downgradient plume migration	✓				Not currently sampled
MW418AR		✓	Biennial	Monitor TCE concentrations within plume; concentrations currently decreasing		✓	Cr	Annual	Arsenic historically below background concentrations; lead historically at non-detect concentrations
MW422A		✓	Biennial	Monitor TCE concentrations in isolated part of plume; concentrations currently decreasing	✓				Not currently sampled
MW424A	✓			Not currently sampled		✓	Cr	Annual	Arsenic historically below background concentrations; lead historically at non-detect concentrations
MW425A		✓	Biennial	Monitor TCE concentrations within plume; concentrations currently decreasing		✓	Cr	Annual	Arsenic historically below background concentrations; lead historically at non-detect concentrations
MW427A		✓	Biennial	Monitor TCE concentrations immediately upgradient of plume	✓				Not currently sampled
MW440A	✓			Cross-gradient from TCE plume		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
MW441A	✓			Cross-gradient from TCE plume	✓				Arsenic historically below background concentrations
MW445A		✓	Annual	Monitor TCE concentrations downgradient of plume; concentrations currently non-detect	✓				Not currently sampled
MW473A		✓	Biennial	Sample for VOCs to monitor TCE concentrations within plume; eliminate sampling for SVOCs		✓	Cr	Annual	Arsenic historically below background concentrations; lead historically at non-detect concentrations
MW475A	✓			TCE concentrations below ACL; well is redundant with MW407A	✓				Not currently sampled
MW476A		✓	Biennial	Monitor TCE concentrations within plume (concentrations display no trend); eliminate sampling for SVOCs	✓				Arsenic historically below background concentrations; chromium and lead historically at non-detect concentrations
MW489A	✓			Not currently sampled		✓	As		Arsenic historically near background concentrations; chromium and lead historically at non-detect concentrations
MW503A	✓			Too far downgradient to provide useful information	✓				Not currently sampled
MW508A		✓	Biennial	Monitor TCE concentrations downgradient of plume; TCE concentrations historically below ACL	✓				Not currently sampled
MW523A		✓	Biennial	Monitor TCE concentrations downgradient of plume; TCE concentrations historically below ACL	✓				Not currently sampled
MW523AB		✓	Biennial	Monitor TCE concentrations in deep part of "A" zone; concentrations display no trend	✓				Not currently sampled
MW524A	✓			TCE concentrations historically non-detect or below ACL; well is redundant with MW523A	✓				Not currently sampled
DW001	✓			Inactive extraction wells should not used for monitoring due to excessive screen length.	✓				Inactive extraction wells should not used for monitoring due to excessive screen length.
DW002	✓			Inactive extraction wells should not used for monitoring due to excessive screen length.	✓				Inactive extraction wells should not used for monitoring due to excessive screen length.
DW003	✓			Inactive extraction wells should not used for monitoring due to excessive screen length.	✓				Inactive extraction wells should not used for monitoring due to excessive screen length.
DW004	✓			Inactive extraction wells should not used for monitoring due to excessive screen length.	✓				Inactive extraction wells should not used for monitoring due to excessive screen length.
Extraction and Monitoring Wells in Monitoring Zone "B"									
EWB1		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system		✓	As, Cr, Pb	Annual	Monitor concentrations of metals in groundwater in areas of metals contamination in soils
EWB2		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
MW402B		✓	Annual	Monitor TCE concentrations within plume; concentrations currently increasing	✓				Not currently sampled
MW407B		✓	Annual	Monitor downgradient extent of TCE plume; concentrations display no trend	✓				Not currently sampled
MW418B		✓	Biennial	Monitor TCE concentrations within plume; concentrations display no trend	✓				Not currently sampled
MW422B		✓	Biennial	Monitor TCE concentrations within plume and cross-gradient from source area	✓				Not currently sampled
MW427B		✓	Biennial	Monitor TCE concentrations upgradient of source area; concentrations historically below ACL	✓				Not currently sampled
MW433B		✓	Annual	Monitor lateral extent of TCE plume; concentrations currently below ACL	✓				Not currently sampled
MW434B	✓			Not currently sampled	✓				Arsenic historically below background concentrations; chromium and lead historically at non-detect concentrations
MW440B	✓			Cross-gradient from TCE plume	✓				Arsenic historically below background concentrations
MW441B	✓			Cross-gradient from TCE plume	✓				Arsenic historically below background concentrations
MW445B		✓	Semi-Annual	Monitor downgradient extent of TCE plume; concentrations display no trend	✓				Not currently sampled
MW448B		✓	Annual	Monitor lateral extent of TCE plume; concentrations currently increasing	✓				Not currently sampled
MW503B	✓			Historically non-detect or below ACL; too far downgradient to provide useful information	✓				Not currently sampled
MW508B		✓	Annual	Monitor downgradient extent of TCE plume; concentrations display no trend	✓				Not currently sampled
MW523B		✓	Annual	Monitor downgradient extent of TCE plume; concentrations non-detect for past 5 years	✓				Not currently sampled

TABLE 4.19 (Continued)
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING PROGRAM
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DDJC-SHARPE, CALIFORNIA

Monitoring Point	Sampling for VOCs ^{a/} /SVOCs ^{b/}			Rationale for VOC/SVOC Sampling to be Retained or Abandoned	Sampling for Other Constituents ^{c/}				Rationale for Sampling for Other Constituents to be Retained or Abandoned
	Abandon/Retain?		Sampling Frequency		Abandon/Retain?		Constituent	Sampling Frequency	
	Abandon	Retain			Abandon	Retain			
Extraction and Monitoring Wells in Monitoring Zone "C"									
EWC1		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWC2		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
EWC3		✓	Semi-Annual	Sample well discharge to provide information regarding performance of extraction system	✓				Not currently sampled
MW402C		✓	Biennial	Monitor TCE concentrations in "C" zone beneath "B"-zone plume; concentrations non-detect for past 5 years	✓				Not currently sampled
MW407C		✓	Annual	Monitor downgradient extent of TCE plume; concentrations non-detect for past 3 years		✓	As	Annual	Monitor concentrations of arsenic in area where arsenic in groundwater exceeds background concentrations
MW418C		✓	Annual	Monitor TCE concentrations within plume; highest concentrations at DDJC-Sharpe, but display no trend	✓				Not currently sampled
MW427C	✓			Too far upgradient to provide useful information; concentrations non-detect for past 5 years	✓				Not currently sampled
MW440C	✓			Cross-gradient from TCE plume	✓				Arsenic historically below background concentrations
MW441C	✓			Cross-gradient from TCE plume	✓				Not currently sampled; arsenic historically below background concentrations
MW445C		✓	Annual	Monitor downgradient extent of TCE plume; concentrations display no apparent trend	✓				Not currently sampled
MW449C		✓	Biennial	Monitor downgradient extent of TCE plume; concentrations historically below ACL	✓				Not currently sampled
MW450C		✓	Biennial	Monitor TCE concentrations within plume	✓				Not currently sampled
MW503C	✓			Historically non-detect or below ACL; too far downgradient to provide useful information	✓				Not currently sampled
MW508C		✓	Biennial	Monitor downgradient extent of TCE plume; concentrations historically non-detect or below ACL	✓				Not currently sampled
Monitoring Wells in Monitoring Zone "D"									
MW402CD	✓			TCE concentrations historically non-detect or below ACL; well is redundant with MW402D	✓				Not currently sampled
MW451CD		✓	Biennial	Monitor "D" zone beneath "C"-zone TCE plume; concentrations non-detect for past 5 years	✓				Not currently sampled
MW524CD	✓			Too far downgradient to provide useful information; concentrations historically non-detect	✓				Not currently sampled
MW401D	✓			Too far upgradient to provide useful information	✓				Not currently sampled
MW402D		✓	Biennial	Monitor "D" zone beneath "C"-zone TCE plume; concentrations historically non-detect or below ACL	✓				Not currently sampled
South Balloon Treatment Plant									
Influent line		✓	Bi-Weekly	Sample influent to provide information regarding performance of treatment system	✓				Air-stripping does not remove non-volatile constituents; influent sampling provides no information regarding treatment
Effluent line		✓	Bi-Weekly	Sample effluent to provide information regarding adherence to discharge standards		✓	e	Variesf/	Sample effluent to provide information regarding adherence to discharge standards

^{a/} VOCs = volatile organic compounds.

^{b/} SVOCs = semi volatile organic compounds.

^{c/} "Other Constituents" include arsenic (As), chromium (Cr), and lead (Pb).

^{d/} "Background" concentrations of metals developed by Radian (1999g) for each of the "A", "B", and "C" monitoring zones.

^{e/} Suite of 23 analytes using trace ICPES; mercury analyzed using USEPA Method SW7470; arsenic analyzed using USEPA Method SW7060 (Radian, 1999g).

^{f/} Bi-weekly for arsenic; monthly for other constituents.

1 MW440A and MW441A, located cross-gradient from the CAH plume in the South
2 Balloon area (Figure 2.13). VOCs historically have not been detected in groundwater
3 samples from these wells. Other wells at locations upgradient or cross-gradient from the
4 VOC source areas at the South Balloon Area also are candidates for abandonment (Table
5 4.19), because the direction of groundwater flow, under natural conditions or with active
6 groundwater extraction, is such that migration of VOCs into these areas is not likely to
7 occur.

8 Multiple wells completed in the same, or similar, depth intervals of the water-bearing
9 unit at similar locations also represent potentially redundant monitoring points. For
10 example, well MW407A is completed in the northwestern part of the dissolved CAH
11 plume, less than 150 feet northwest of well MW475A. Both wells are routinely
12 monitored, although one well would probably provide sufficient information for the
13 purposes of satisfying the two primary objectives of monitoring (above). Therefore, one
14 of the two wells may be a candidate for abandonment (Table 4.19).

15 Active and inactive groundwater EWs require additional consideration. EWs
16 generally are screened through depth intervals of greater length than are monitoring
17 wells, in order to maximize the ability of the EW to produce water. This means that a
18 sample of groundwater collected from an EW is not representative of conditions within a
19 discrete interval of the water-bearing unit, but rather is a composite sample,
20 representative of conditions in several depth intervals. Furthermore, because an EW
21 withdraws groundwater from some volume of the groundwater system surrounding the
22 well, the concentration of a constituent in the effluent discharged from the well cannot be
23 regarded as representative of conditions at the well location. Rather, the constituent
24 concentration is an average value, representative of concentrations throughout the volume
25 from which the well extracts groundwater. Therefore, the results of monitoring effluent
26 from an EW generally should not be used as indicators of local chemical conditions.
27 However, periodic monitoring of EW discharge can provide an indication of the rate of
28 removal of chemical mass from the subsurface, and as such generates information of use
29 in evaluating long-term performance of the extraction (and treatment) system. Therefore,
30 periodic monitoring of EW discharge should continue in those wells within the extraction

network that remain in active service. However, if an EW is removed from service (e.g., wells DW001, DW002, DW003, and DW004 in the South Balloon area), it should no longer be used for monitoring due to excessive screen length.

The results of the qualitative evaluation of the complete monitoring network at the South Balloon Area are presented in Table 4.19. Recommendations for retaining or abandoning each existing monitoring point in the South Balloon area also are presented in Table 4.19, together with rationale for the recommendations.

4.3.2 Temporal Statistical Evaluation of South Balloon Monitoring Program

Temporal data (chemical concentrations measured at different points in time) can be examined visually, or with statistical tests, to evaluate plume stability. If removal of chemical mass is occurring in the subsurface as a consequence of attenuation processes or operation of the remediation system, mass removal will be apparent as a decrease in chemical concentrations through time at a particular sampling location, as a decrease in chemical concentrations with increasing distance from chemical source areas, and/or as a change in the suite of chemicals through time or with increasing migration distance.

Temporal chemical-concentration data can be evaluated by plotting contaminant concentrations through time for individual monitoring or EWs (Figure 4.28), or by plotting contaminant concentrations versus downgradient distance from the contaminant source for several wells along the groundwater flowpath, over several monitoring events. Plotting temporal concentration data is recommended for any analysis of plume stability (Wiedemeier and Haas, 1999); however, visual identification of trends in plotted data may be a subjective process, particularly (as is likely) if the concentration data do not have a uniform trend, but are variable through time (Figure 4.28).

The possibility of arriving at incorrect conclusions regarding plume stability on the basis of visual examination of temporal concentration data can be reduced by examining temporal trends in chemical concentrations using various statistical procedures, including regression analyses and the Mann-Kendall test for trends. The Mann-Kendall non-parametric test (Gibbons, 1994) is well suited for application to the evaluation of environmental data because the sample size can be small (as few as four data points), no

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2 **Figure 4.28 Conceptual Representation of Temporal Trends and Temporal**
3 **Variation in Concentrations**

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1 assumptions are made regarding the underlying statistical distribution of the data, and the
2 test can be adapted to account for seasonal variations in the data. The Mann-Kendall test
3 statistic can be calculated at a specified level of confidence to evaluate whether a
4 temporal trend is present in contaminant concentrations detected through time in samples
5 from an individual well. If a trend is determined to be present, a non-parametric slope of
6 the trend line (change per unit time) can also be estimated using the test procedure. A
7 negative slope (indicating decreasing contaminant concentrations through time) or a
8 positive slope (increasing concentrations through time) provides statistical confirmation
9 of temporal trends that may have been identified visually (Figure 4.18).

10 The amount of information obtained from periodic monitoring at a particular
11 monitoring well can be evaluated by considering the location of the well within (or
12 outside of) the contaminant plume, the location of the well with respect to potential
13 receptor exposure points, and the presence or absence of temporal trends in contaminant
14 concentrations in samples collected from the well. The degree to which the amount and
15 quality of information obtainable at a particular monitoring point serves the two primary
16 objectives of monitoring (temporal and spatial objectives) must be considered in this
17 evaluation. For example, the continued occurrence of a contaminant in groundwater at
18 concentrations below the detection limit at a monitoring location provides no information
19 about temporal trends in contaminant concentrations, or about the extent to which
20 contaminant migration is occurring, unless the monitoring location lies along a
21 groundwater flowpath between a contaminant source and a potential receptor exposure
22 point. Therefore, a monitoring well having a history of contaminant concentrations
23 below detection limits may be providing no useful information, depending on its location.

24 A trend of increasing contaminant concentrations in groundwater at a location between
25 a contaminant source and a potential receptor exposure point may represent information
26 critical in evaluating whether contaminants may migrate to the exposure point, thereby
27 completing an exposure pathway. Identification of a trend of decreasing contaminant
28 concentrations at the same location may be useful in evaluating decreases in a plume's
29 areal extent, but does not represent information that is critical to the protection of a
30 potential receptor. Similarly, a trend of decreasing contaminant concentrations in

groundwater near a contaminant source may represent important information regarding the progress of remediation near, and downgradient of the source, while identification of a trend of increasing contaminant concentrations at the same location does not provide as much useful information regarding contaminant conditions. By contrast, the absence of a temporal trend in contaminant concentrations at a particular location within, or downgradient of a plume, indicates that virtually no additional information can be obtained by continued monitoring of groundwater at that location, in that the results of continued monitoring through time are likely to fall within the historic range of concentrations that have already been detected (Figure 4.29). Continued monitoring at locations where no temporal trend in contaminant concentrations is present serves merely to confirm the results of previous monitoring activities at that location. The relative amounts of information generated by the results of temporal trend evaluation at monitoring points near, upgradient of, and downgradient from contaminant sources are presented schematically as follow:

Monitoring Point Near Contaminant Source

Relatively less information

Nondetect or no trend



Increasing trend in concentrations

Relatively more information

Decreasing trend in concentrations

Monitoring Point Upgradient from Contaminant Source

Relatively less information

Nondetect or no trend



Decreasing trend in concentrations

Relatively more information

Increasing trend in concentrations

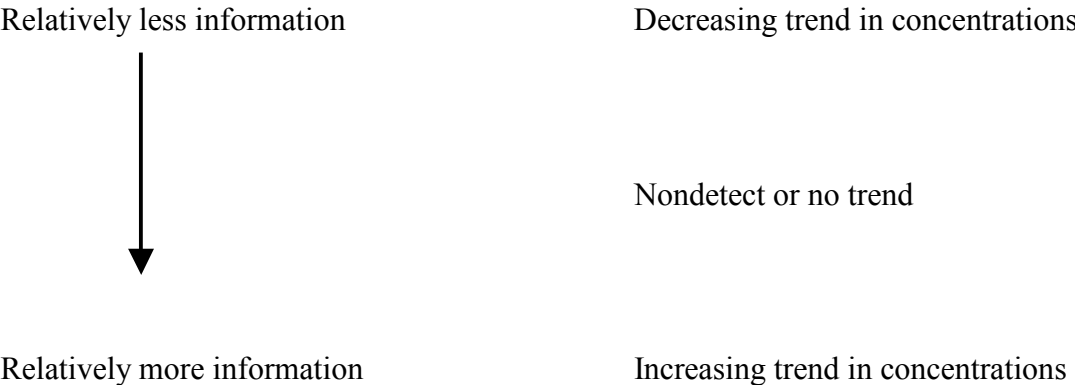
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2 **Figure 4.29 Conceptual Representation of Continued Monitoring at Locations**
3 **where No Temporal Trend in Concentrations is Present**

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Monitoring Point Downgradient from Contaminant Source



BTEX constituents and 8 VOCs (carbon tetrachloride, chlorobenzene, 1,2-DCA, *cis*-1,2-DCE, *trans*-1,2-DCE, PCE, TCE, and vinyl chloride) historically have been detected in groundwater samples from one or more monitoring wells in the South Balloon area, at concentrations that exceed the ACL concentrations for the compounds. The monitoring results for each of the BTEX constituents and 8 VOCs, together with total chromium, chromium(VI), and lead, detected in each well in the current monitoring program were examined for trends using the Mann-Kendall test (Table 4.20). The objective of the evaluation was to identify those wells having increasing or decreasing concentration trends for each COC, and to consider the quality of information represented by the existence or absence of concentration trends in terms of the location of each monitoring point.

Examination of the results of Mann-Kendall temporal trend analyses for representative VOCs (e.g., TCE) enable areas of the COC plume within which chemical concentrations are increasing, decreasing, or stable to be readily identified. Summary results of the temporal trend analyses are presented in Table 4.20. Color coding of the table entries denotes the presence/absence of temporal trends, and allows those monitoring points having nondetectable concentrations, decreasing or increasing concentrations, or no discernible trend in concentrations to be readily identified. Monitoring points at which chemical concentrations display no discernible temporal trend generally represent points generating the least amount of useful information. Depending on the location of the monitoring point, consistently nondetected concentrations of chemicals through time can

TABLE 4.20
RESULTS OF TEMPORAL TREND ANALYSIS OF SOUTH BALLOON GROUNDWATER MONITORING NETWORK
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monitoring Zone "A"															
Well ID	Total Chromium	Chromium (VI)	Lead	Benzene	Toluene	Ethylbenzene	Total Xylenes	Carbon Tetrachloride	Chlorobenzene	1,2-DCA	cis-1,2-DCE	trans-1,2-DCE	PCE	TCE	Vinyl Chloride
MW401A	ND	no trend	ND	< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	ND	ND	ND	ND	no trend	ND
MW402A	no trend	< 4 meas	no trend	ND	ND	ND	< 4 meas	ND	ND	ND	no trend	ND	ND	no trend	ND
MW403A	no trend	no trend	no trend	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW406A	+	< 4 meas	ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW407A	no trend		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	-	ND	ND	no trend	ND
MW415A				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	no trend	no trend	ND
MW417A				< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	-	ND	ND	ND	-	ND
MW418AR	+	< 4 meas	no trend	ND	ND	ND	ND	ND	ND	no trend	-	ND	ND	no trend	ND
MW422A				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW424A	no trend	no trend	no trend	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	-	ND	ND	no trend	ND
MW425A	+	-	ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	no trend	ND	no trend	no trend	ND
MW427A	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	-	ND	ND	no trend	ND
MW440A		< 4 meas		< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW441A				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	-	ND	ND	no trend	ND
MW445A				ND	ND	ND	ND	-	ND	ND	ND	ND	no trend	no trend	ND
MW473A	+	< 4 meas	ND	ND	ND	ND	ND	ND	ND	no trend	-	ND	ND	no trend	ND
MW475A				ND	ND	ND	< 4 meas	ND	ND	ND	-	-	ND	no trend	ND
MW476A	no trend	< 4 meas	-	ND	-	ND	ND	ND	-	-	no trend	-	-	no trend	ND
MW489A	< 4 meas	< 4 meas	< 4 meas					ND	ND	ND	ND	ND	ND	no trend	ND
MW503A				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW508A				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	-	ND	ND	ND	-	ND
MW523A				ND	ND	ND	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW523AB				ND	ND	ND	ND	ND	ND	ND	no trend	ND	ND	no trend	ND
MW524A				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	no trend	ND
Monitoring Zone "B"															
Well ID	Total Chromium	Chromium (VI)	Lead	Benzene	Toluene	Ethylbenzene	Total Xylenes	Carbon Tetrachloride	Chlorobenzene	1,2-DCA	cis-1,2-DCE	trans-1,2-DCE	PCE	TCE	Vinyl Chloride
MW402B	no trend		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	no trend	ND	ND	-	ND
MW407B	no trend		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	-	ND	ND	-	ND
MW418B	ND		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	no trend	ND	ND	-	ND
MW422B				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW427B	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
MW433B	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	no trend	ND	no trend	no trend	ND
MW434B	no trend	< 4 meas	ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	+	ND	ND	-	ND
MW440B		< 4 meas		< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	+	ND
MW441B				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	+	ND
MW445B				< 4 meas	ND	ND	< 4 meas	no trend	ND	ND	+	ND	+	+	ND
MW448B				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW503B				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW508B				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	no trend	ND	ND	ND	+	ND
MW523B				ND	ND	ND	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND

TABLE 4.20 (Continued)
RESULTS OF TEMPORAL TREND ANALYSIS OF SOUTH BALLOON GROUNDWATER MONITORING NETWORK
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monitoring Zone "C"															
Well ID	Total Chromium	Chromium (VI)	Lead	Benzene	Toluene	Ethylbenzene	Total Xylenes	Carbon Tetrachloride	Chlorobenzene	1,2-DCA	cis-1,2-DCE	trans-1,2-DCE	PCE	TCE	Vinyl Chloride
MW402C	no trend		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
MW407C	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	no trend	ND	ND	-	ND
MW418C	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	no trend	ND	ND	-	no trend
MW427C	< 4 meas		ND	< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
MW440C		< 4 meas		< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	+	ND
MW441C				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	+	ND
MW445C				< 4 meas	ND	< 4 meas	ND	+	ND	ND	+	ND	+	+	ND
MW449C				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	no trend	ND
MW450C				< 4 meas	< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	ND	ND	ND	no trend	ND
MW503C				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
MW508C				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
Monitoring Zone "D"															
Well ID	Total Chromium	Chromium (VI)	Lead	Benzene	Toluene	Ethylbenzene	Total Xylenes	Carbon Tetrachloride	Chlorobenzene	1,2-DCA	cis-1,2-DCE	trans-1,2-DCE	PCE	TCE	Vinyl Chloride
MW402CD				< 4 meas	< 4 meas	< 4 meas	no trend	ND	ND	ND	ND	ND	ND	-	ND
MW451CD				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND
MW524CD				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW401D				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	ND
MW402D				< 4 meas	< 4 meas	< 4 meas	< 4 meas	ND	ND	ND	ND	ND	ND	-	ND

^{a/} COC = contaminant of concern.

ND	= Constituent has not been detected in well monitoring history.
no trend	= No statistically significant temporal trend in concentration.
+	= Statistically significant increasing trend in concentration.
-	= Statistically significant decreasing trend in concentration.
< 4 meas	= Fewer than four measurements at the monitoring well.
	= No data available for the monitoring well.

1 also represent relatively little information. Depending upon location (as discussed
2 above), monitoring points at which one or more of the COCs display increasing or
3 decreasing temporal trends in concentrations represent points at which monitoring should
4 probably continue.

5 **4.3.3 Spatial Statistical Evaluation**

6 Spatial statistical techniques can also be applied to the design and evaluation of
7 monitoring programs to assess the quality of information generated during monitoring,
8 and to optimize monitoring networks. Parsons examined historic groundwater
9 monitoring data collected during the period July 1996 through July 2000, using the
10 MAROS tool in a screening-level evaluation of the monitoring network currently utilized
11 at the South Balloon area.

12 The MAROS (Monitoring and Remediation Optimization System) (Groundwater
13 Services, Inc. [GSI], 1999) tool is a software program, developed by GSI on behalf of
14 AFCEE, intended for use in optimizing monitoring programs. The MAROS software,
15 currently being used in a trial (“beta”) version, actually consists of a set of small
16 programs (macros) that operate within an electronic database environment (Microsoft™
17 Access97®) and perform certain mathematical or statistical functions using data that have
18 been loaded into the database. MAROS makes extensive use of graphical user interfaces
19 (GUIs), and appears to have been developed primarily to assist non-technical personnel
20 (e.g., facility environmental managers) in the organization, preliminary evaluation, and
21 presentation of monitoring data.

22 The MAROS tool provides a simple spatial statistical method, based on a weighted
23 "area-of-influence" approach (implemented using Delauney triangulation), for optimizing
24 the locations of monitoring points. A limitation of the MAROS tool is that only five
25 COCs can be examined in a single simulation. Because TCE has been the COC detected
26 most frequently, and at the greatest number of sampling locations, TCE was selected as
27 the “indicator VOC” for use in the screening-level spatial evaluation. A spatial
28 evaluation for metallic/inorganic constituents also was considered; however, the
29 concentrations of the two inorganic constituents most frequently detected in groundwater

1 (arsenic and chromium) demonstrate erratic spatial variability; and it was decided to
2 examine TCE only. A further limitation of MAROS is that the tool can process
3 monitoring data from only 40 wells in a simulation. Therefore, the monitoring results
4 from several wells in the South Balloon program were eliminated from the MAROS
5 simulations. As a consequence of concerns regarding representativeness of monitoring
6 data collected at extraction wells (Section 4.3.1), active and inactive extraction wells also
7 were excluded from the evaluation.

8 In application, the concentrations of TCE detected in groundwater samples from each
9 monitoring well were used in the Delaune method (as implemented in the MAROS tool)
10 to calculate a unitless slope factor for each monitoring well included in the current
11 monitoring program (Appendix E). The unitless slope factor calculated for each
12 monitoring well represents the relative worth of monitoring data associated with that well
13 in relation to the entire monitoring well field, with higher values of slope factor
14 indicating relatively greater worth; and each monitoring point in the network can be
15 ranked according to the relative value of information generated by sampling at that point.
16 Wells having a slope factor less than about 0.15 were regarded as contributing relatively
17 little information; wells having a slope factor between 0.16 and 0.40 contribute a
18 moderate amount of information; and wells having a slope factor greater than 0.40
19 contribute the most information to the monitoring program. Wells that provided
20 relatively greater amounts of information were recommended for retention in the
21 program, on the basis of the spatial evaluation (Table 4.21); wells that provided the least
22 amount of information were recommended for removal from the program.

23 The procedure that was followed in conducting the spatial evaluation was not rigorous,
24 but rather was intended to be a screening-level simulation to evaluate whether spatial
25 techniques could successfully be applied to assist in optimizing the groundwater
26 monitoring network. The results of the screening simulation suggest that a more detailed
27 evaluation, possibly using geostatistical techniques, could be useful in refining the
28 existing monitoring program.

TABLE 4.21
SUMMARY OF EVALUATION OF CURRENT GROUNDWATER MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monitoring Point	Qualitative Evaluation				Temporal Statistical Evaluation				Spatial Evaluation		Summary			
	Sampling for VOCs ^{b/}		Sampling for Other Constituents ^{c/}		Sampling for VOCs		Sampling for Other Constituents		Sampling for VOCs		Sampling for VOCs		Sampling for Other Constituents	
	Abandon	Retain	Abandon	Retain	Abandon	Retain	Abandon	Retain	Abandon	Retain	Abandon	Retain	Abandon	Retain
Extraction and Monitoring Wells in Monitoring Zone "A"														
EWA1		✓	✓		-- ^{d/}	--	--	--	--	--		✓	✓	
EWA2		✓	✓		--	--	--	--	--	--		✓	✓	
EWA3		✓	✓		--	--	--	--	--	--		✓	✓	
EWA4		✓	✓		--	--	--	--	--	--		✓	✓	
EWA5		✓	✓		--	--	--	--	--	--		✓	✓	
EWA6		✓	✓		--	--	--	--	--	--		✓	✓	
EWA7		✓		✓	--	--	--	--	--	--		✓		✓
EWA8		✓		✓	--	--	--	--	--	--		✓		✓
EWA9		✓		✓	--	--	--	--	--	--		✓		✓
EWA10		✓		✓	--	--	--	--	--	--		✓		✓
MW401A	✓			✓	✓		✓		✓		✓			✓
MW402A	✓			✓	✓		✓			✓		✓		✓
MW403A	✓			✓	✓		✓			✓		✓		✓
MW406A		✓		✓	✓			✓		✓		✓		✓
MW407A		✓		✓		✓	✓			✓		✓		✓
MW415A		✓	✓		✓		--	--		✓		✓	✓	
MW417A		✓	✓		✓		--	--	--	--		✓	✓	
MW418AR		✓		✓		✓		✓	--	--		✓		✓
MW422A		✓	✓		✓		--	--		✓		✓	✓	
MW424A	✓			✓	✓		✓			✓		✓		✓
MW425A		✓		✓	✓			✓		✓		✓		✓
MW427A		✓	✓			✓	✓			✓		✓	✓	
MW440A	✓			✓	✓		--	--		✓		✓		✓
MW441A	✓		✓		✓		--	--		✓		✓	✓	
MW445A		✓	✓		✓		--	--		✓		✓	✓	
MW473A		✓		✓		✓		✓		✓		✓		✓
MW475A	✓		✓			✓	--	--	✓		✓		✓	
MW476A		✓	✓			✓		✓		✓		✓		✓
MW489A	✓			✓	✓		✓			✓		✓		✓
MW503A	✓		✓		✓		--	--	--	--	✓		✓	
MW508A		✓	✓		✓		--	--	--	--		✓	✓	
MW523A		✓	✓		✓		--	--	--	--		✓	✓	
MW523AB		✓	✓		✓		--	--	--	--		✓	✓	
MW524A	✓		✓		✓		--	--	--	--	✓		✓	
DW001	✓		✓		--	--	--	--	--	--	✓		✓	
DW002	✓		✓		--	--	--	--	--	--	✓		✓	
DW003	✓		✓		--	--	--	--	--	--	✓		✓	
DW004	✓		✓		--	--	--	--	--	--	✓		✓	
Extraction and Monitoring Wells in Monitoring Zone "B"														
EWB1		✓		✓	--	--	--	--	--	--		✓		✓
EWB2		✓	✓		--	--	--	--	--	--		✓	✓	
MW402B		✓	✓			✓	✓		✓			✓	✓	
MW407B		✓	✓		✓		✓			✓		✓	✓	
MW418B		✓	✓			✓	✓			✓		✓	✓	
MW422B		✓	✓		✓		--	--		✓		✓	✓	
MW427B		✓	✓		✓		✓			✓		✓	✓	
MW433B		✓	✓		✓		✓		✓			✓	✓	
MW434B	✓		✓			✓	✓		✓			✓	✓	
MW440B	✓		✓			✓	--	--	✓			✓	✓	
MW441B	✓		✓			✓	--	--	✓			✓	✓	
MW445B		✓	✓			✓	--	--		✓		✓	✓	
MW448B		✓	✓		✓		--	--		✓		✓	✓	
MW503B	✓		✓		✓		--	--	--	--	✓		✓	
MW508B		✓	✓			✓	--	--	--	--		✓	✓	
MW523B		✓	✓		✓		--	--	--	--		✓	✓	
Extraction and Monitoring Wells in Monitoring Zone "C"														
EW C1		✓	✓		--	--	--	--	--	--		✓	✓	
EW C2		✓	✓		--	--	--	--	--	--		✓	✓	
EW C3		✓	✓		--	--	--	--	--	--		✓	✓	
MW402C		✓	✓			✓	✓			✓		✓	✓	
MW407C		✓		✓	✓		✓		✓			✓		✓
MW418C		✓	✓			✓	✓		✓			✓	✓	
MW427C	✓		✓			✓	✓		✓			✓	✓	
MW440C	✓		✓			✓	--	--		✓		✓	✓	
MW441C	✓		✓			✓	--	--	✓			✓	✓	
MW445C		✓	✓			✓	--	--		✓		✓	✓	
MW449C		✓	✓		✓		--	--	✓			✓	✓	
MW450C		✓	✓		✓		--	--		✓		✓	✓	
MW503C	✓		✓		✓		--	--	--	--	✓		✓	
MW508C		✓	✓		✓		--	--	--	--		✓	✓	
Monitoring Wells in Monitoring Zone "D"														
MW402CD	✓		✓			✓	--	--	✓			✓	✓	
MW451CD		✓	✓		✓		--	--	✓			✓	✓	
MW524CD	✓		✓		✓		--	--	--	--	✓		✓	
MW401D	✓		✓			✓	--	--	✓			✓	✓	
MW402D		✓	✓			✓	--	--	✓			✓	✓	
South Balloon Treatment Plant														
Influent line		✓	✓		--	--	--	--	--	--		✓	✓	
Effluent line ^{e,/f/}		✓		✓	--	--	--	--	--	--		✓		✓

^{a/} "Current" monitoring program is sampling program proposed for 2000 by Radian (1999g) (Table 4.17).
^{b/} VOCs = volatile organic compounds.
^{c/} "Other Constituents" include arsenic, chromium, and lead.
^{d/} A dash (--) indicates that a particular screening method was not applicable to that well.
^{e/} Suite of 23 analytes using trace ICPEs; mercury analyzed using USEPA Method SW7470; arsenic analyzed using USEPA Method SW7060 (Radian, 1999g).
^{f/} Bi-weekly for arsenic; monthly for other constituents.

4.3.4 Sampling Technology Optimization

A field evaluation of diffusion-sampling technology was recently completed (Parsons, 2001) at a nearby DLA facility (DDJC-Tracy), to compare the effectiveness of this VOC groundwater sampling method with the standard sampling method (low-flow/minimal-drawdown purging, or micropurging) currently used for VOC sampling in the DDJC-Tracy LTM program. Field sampling was conducted using diffusion samplers developed by the US Geological Survey (Vroblesky and Campbell, 2000). The pilot-scale evaluation demonstrated that diffusion sampling results are comparable to those obtained using the traditional micropurge method in approximately 80 percent of the wells in which the diffusion samplers were completely submerged.

Diffusion sampling for VOCs can provide several benefits over conventional (e.g. micropurging) sampling, including low capital costs, reduced sample-collection time, and production of no purge water (which requires subsequent handling as investigation-derived waste). The net result is that the cost per sample, collected using diffusion-sampling techniques, is approximately one-third to one-fifth the cost per sample collected using conventional or micropurging techniques. Although diffusion sampling would not be appropriate for use at all of the monitoring wells currently included in the DDJC-Sharpe LTM program, results of the pilot-scale evaluation of diffusion samplers at DDJC-Tracy suggests that the possibility of incorporating diffusion sampling into future monitoring programs should be evaluated for DDJC-Sharpe. In the absence of detailed information regarding the locations and numbers of monitoring wells equipped with dedicated pumps, it is not possible to estimate the potential cost savings that might result from implementation of diffusion-sampling technology.

4.3.5 Summary of Monitoring Network Evaluation

The existing groundwater monitoring network at the South Balloon area of DDJC-Sharpe, consisting of 48 monitoring wells, 15 active extraction wells, and 4 inactive production wells from which samples are periodically collected, was evaluated using qualitative hydrogeologic knowledge, temporal statistical techniques, and simple, screening-level spatial statistics. At each stage in the evaluation, monitoring points that provided relatively greater amounts of information regarding the occurrence and

1 distribution of COCs in groundwater were identified, and were distinguished from those
2 monitoring points that provided relatively lesser amounts of information. The results of
3 the qualitative, temporal, and spatial evaluations are summarized in Table 4.21.

4 The results of evaluations were combined to generate a subset of the monitoring
5 network that could potentially provide information sufficient to address the primary
6 objectives of monitoring, at reduced cost. Wells not retained in the reduced monitoring
7 network could be abandoned, with relatively little loss of information. The results of the
8 evaluation were combined and summarized in accordance with the following algorithm:

- 9 1. The effluent of each active EW will be periodically sampled and analyzed. If
10 an EW goes off-line or is otherwise removed from the system, monitoring at
11 that well will cease.
- 12 2. Each well retained in the monitoring network on the basis of the qualitative
13 hydrogeologic evaluation is recommended to be retained in the reduced
14 monitoring network.
- 15 3. Each well retained in the monitoring network on the basis of the temporal
16 statistical evaluation is recommended to be retained in the reduced monitoring
17 network.
- 18 4. Each well retained in the monitoring network on the basis of the spatial
19 evaluation is recommended to be retained in the reduced monitoring network.
- 20 5. Any well recommended for abandonment on the basis of the qualitative,
21 temporal, and spatial evaluations can be removed from the network with
22 virtually no loss of information.
- 23 6. If no information is available regarding the value of monitoring for a particular
24 well on the basis of temporal statistics (e.g., if samples from the well
25 historically have not been analyzed for chromium), then the value of
26 information for that well is based on the qualitative and spatial evaluations, and
27 the results of the temporal statistical evaluation are not considered.

- 1 7. If no information is available regarding the value of monitoring for a particular
2 well on the basis of the spatial evaluation (e.g., extraction wells were not
3 included in the MAROS evaluation), then the value of information for that well
4 is based on the qualitative and temporal evaluations, and results of the spatial
5 evaluation are not considered.
- 6 8. Any well recommended for abandonment on the basis of the qualitative and
7 temporal evaluations can be removed from the network with little loss of
8 information, as long as that well has not been recommended for retention on the
9 basis of the spatial evaluation.
- 10 9. Any well recommended for abandonment on the basis of one evaluation (e.g.,
11 qualitative hydrogeology) and for retention on the basis of another evaluation
12 (e.g., temporal) is recommended for retention in the reduced network.
- 13 10. Only those wells recommended for abandonment on the basis of all three
14 evaluations, or on the basis of the qualitative and temporal evaluations (with no
15 recommendation resulting from the spatial evaluation) should be removed from
16 the network.

17 The summary results of the evaluations (Table 4.21) indicate that the inactive
18 production wells (wells DW001, DW002, DW003, and DW004) and four of the existing
19 monitoring wells (monitoring wells MW503A, MW503B, MW503C, and MW524CD)
20 could be removed from the monitoring network with little loss of information. Sampling
21 and analyses for metals and inorganic constituents at a number of wells also could be
22 eliminated, and the frequency of sampling could be reduced at those wells that are
23 retained for monitoring of metals. On the other hand, wells MW402A, MW403A,
24 MW489A, and MW434B, which currently are sampled only for metals and inorganic
25 constituents (Table 4.17), are recommended to be sampled for VOCs, primarily as a
26 consequence of the potential value of temporal statistical information that may be
27 obtained from continued, periodic monitoring at these locations (Tables 4.20 and 4.21).

1 Parsons recommends that sampling of monitoring wells for bromacil be discontinued,
2 because the occurrence of bromacil in groundwater at DDJC-Sharpe is apparently the
3 result of normal and intended use of the herbicide in nearby agricultural applications
4 (Section 2.3.2.1). Sampling for hexavalent chromium also could be discontinued,
5 because no regulatory standard exists for hexavalent chromium in groundwater. Periodic
6 sampling of the treatment plant influent and effluent streams should continue as currently
7 implemented, to ensure compliance with NPDES and other discharge standards.

8 As a consequence of the conservative nature of the algorithm used, only four
9 monitoring wells and four inactive production wells were identified as potential
10 candidates for elimination from the monitoring network. A reduced monitoring network,
11 consisting of 44 monitoring wells and 15 active EWs would be adequate to address the
12 two primary objectives of monitoring. Furthermore, as a consequence of the great
13 distances and long travel times to potential exposure points, and the generally successful
14 hydraulic capture/containment that is occurring with active groundwater extraction,
15 groundwater monitoring at most locations should be conducted no more frequently than
16 biennially.

17 Cumulative costs for the revised monitoring program at the South Balloon area were
18 estimated, assuming that the revised monitoring program were to be fully implemented,
19 that no other changes to remediation systems will occur (e.g., no additional extraction
20 wells are removed from service, and all monitoring wells remain in service through the
21 estimated 75-year period required to attain ACL concentration cleanup objectives). The
22 estimated annual costs associated with the revised groundwater monitoring program at
23 the South Balloon area (Table 4.22) are summarized in Table 4.23. Assuming that the
24 revised monitoring program is continued for an additional 75 years, the cumulative cost
25 of the monitoring program (in constant 2000 dollars) is estimated to be approximately
26 \$10,000,000 (Table 4.23).

27

TABLE 4.22
REVISED GROUNDWATER MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monitoring Point	Laboratory Analyses (Frequency)			
	VOCs ^{b/} (Method SW8021)	Arsenic (Method SW6010/6010B)	Total Chromium (Method SW6010/6010B)	Lead (Method SW6010/6010B)
Extraction and Monitoring Wells in Monitoring Zone "A"				
EWA1	Semi-Annual			
EWA2	Semi-Annual			
EWA3	Semi-Annual			
EWA4	Semi-Annual			
EWA5	Semi-Annual			
EWA6	Semi-Annual			
EWA7	Semi-Annual	Annual	Annual	Annual
EWA8	Semi-Annual	Annual	Annual	Annual
EWA9	Semi-Annual	Annual	Annual	Annual
EWA10	Semi-Annual	Annual	Annual	Annual
MW401A			Annual	Annual
MW402A	Annual		Annual	Annual
MW403A	Biennial	Annual		
MW406A	Biennial		Annual	Annual
MW407A	Biennial	Annual		
MW415A	Biennial			
MW417A	Biennial			
MW418AR	Biennial		Annual	
MW422A	Biennial			
MW424A	Biennial		Annual	
MW425A	Biennial		Annual	
MW427A	Biennial			
MW440A	Biennial	Annual	Annual	Annual
MW441A	Biennial			
MW445A	Annual			
MW473A	Biennial		Annual	
MW475A	Biennial			
MW476A	Biennial			Biennial
MW489A	Biennial	Annual		
MW508A	Biennial			
MW523A	Biennial			
MW523AB	Biennial			
Extraction and Monitoring Wells in Monitoring Zone "B"				
EWB1	Semi-Annual	Annual	Annual	Annual
EWB2	Semi-Annual			
MW402B	Annual			
MW407B	Annual			
MW418B	Biennial			
MW422B	Biennial			
MW427B	Biennial			
MW433B	Annual			
MW434B	Annual			
MW440B	Biennial			
MW441B	Biennial			
MW445B	Semi-Annual			
MW448B	Annual			
MW508B	Annual			
MW523B	Annual			
Extraction and Monitoring Wells in Monitoring Zone "C"				
EWC1	Semi-Annual			
EWC2	Semi-Annual			
EWC3	Semi-Annual			
MW402C	Biennial			
MW407C	Annual	Annual		
MW418C	Annual			
MW427C	Biennial			
MW440C	Biennial			
MW441C	Biennial			
MW445C	Annual			
MW449C	Biennial			
MW450C	Biennial			
MW508C	Biennial			
Monitoring Wells in Monitoring Zone "D"				
MW402CD	Annual			
MW451CD	Biennial			
MW401D	Biennial			
MW402D	Biennial			
South Balloon Treatment Plant				
Influent line	Bi-Weekly			
Effluent line	Bi-Weekly	Weekly ^{c/}		

TABLE 4.22 (Continued)
REVISED GROUNDWATER MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monitoring Point	Laboratory Analyses (Frequency)			
	VOCs ^{b/} (Method SW8021)	Arsenic (Method SW6010/6010B)	Total Chromium (Method SW6010/6010B)	Lead (Method SW6010/6010B)

^{a/} Revised groundwater monitoring program based on program proposed for 2000 by Radian (
^{b/} VOCs = volatile organic compounds.
^{c/} Suite of 23 analytes using trace ICPES; mercury analyzed using USEPA Method SW7470; arsenic and
USEPA Method SW7060 (Radian, 1999g).

TABLE 4.23
ESTIMATED COSTS ASSOCIATED WITH REVISED MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

16 Wells Sampled Semi-Annually				
Cost type	Quantity	Units	Unit Cost	Cost
Labor for sample collection				
1 person at \$65/hr	32	hours	\$ 65.00	\$ 2,080.00
Labor for data validation and data management				
1 person at \$65/hr	32	hours	\$ 65.00	\$ 2,080.00
Reporting				
160 hours at \$80/hr	160	hours	\$ 80.00	\$ 12,800.00
Laboratory Analyses				
VOCs by Method SW8021B (primary samples + QA/QC)	21	samples	\$ 155.00	\$ 3,255.00
Other Direct Costs				
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	3	days	\$ 400.00	\$ 1,200.00
Vehicle Rental (1 vehicle for 1 day)	3	days	\$ 55.00	\$ 165.00
Miscellaneous Field Supplies				\$ 100.00
SUBTOTAL SEMI-ANNUAL COSTS				\$ 21,680.00
14 Wells Sampled Annually				
Cost type	Quantity	Units	Unit Cost	Cost
Labor for sample collection				
1 person at \$65/hr	28	hours	\$ 65.00	\$ 1,820.00
Labor for data validation and data management				
1 person at \$65/hr	28	hours	\$ 65.00	\$ 1,820.00
Reporting				
140 hours at \$80/hr	140	hours	\$ 80.00	\$ 11,200.00
Laboratory Analyses				
VOCs by Method SW8021B (primary samples + QA/QC)	17	samples	\$ 155.00	\$ 2,635.00
Metals by Method SW6010/6010B (primary samples +QA/QC)	20	samples	\$ 75.00	\$ 1,500.00
Other Direct Costs				
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	3	days	\$ 400.00	\$ 1,200.00
Vehicle Rental (1 vehicle for 1 day)	3	days	\$ 55.00	\$ 165.00
Miscellaneous Field Supplies				\$ 100.00
SUBTOTAL ANNUAL COSTS				\$ 20,440.00
33 Wells Sampled Biennially				
Cost type	Quantity	Units	Unit Cost	Cost
Labor for sample collection				
1 person at \$65/hr	66	hours	\$ 65.00	\$ 4,290.00
Labor for data validation and data management				
1 person at \$65/hr	66	hours	\$ 65.00	\$ 4,290.00
Reporting				
330 hours at \$80/hr	330	hours	\$ 80.00	\$ 26,400.00
Laboratory Analyses				
VOCs by Method SW8021B (primary samples + QA/QC)	21	samples	\$ 155.00	\$ 3,255.00
Metals by Method SW6010/6010B (primary samples +QA/QC)	3	samples	\$ 75.00	\$ 225.00
Other Direct Costs				
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	8	days	\$ 400.00	\$ 3,200.00
Vehicle Rental (1 vehicle for 1 day)	8	days	\$ 55.00	\$ 440.00
Miscellaneous Field Supplies				\$ 1,000.00
SUBTOTAL BIENNIAL COSTS				\$ 43,100.00

TABLE 4.23 (Continued)
ESTIMATED COSTS ASSOCIATED WITH REVISED MONITORING PROGRAM^{a/}
SOUTH BALLOON AREA
REMEDIAL PROCESS OPTIMIZATION PHASE II REPORT
DDJC-SHARPE, CALIFORNIA

Monthly Treatment Plant Influent/Effluent Sampling					
Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
1 person at \$65/hr	8	hours	\$	65.00	\$ 520.00
Labor for data validation and data management					
1 person at \$65/hr	8	hours	\$	65.00	\$ 520.00
Reporting					
10 hours at \$80/hr	10	hours	\$	80.00	\$ 800.00
Laboratory Analyses					
VOCs by Method SW8021B (primary samples + QA/QC)	6	samples	\$	155.00	\$ 930.00
Selenium by Method SW7740 (primary sample +QA/QC)	3	samples	\$	30.00	\$ 90.00
Arsenic by Method 7060 (primary sample +QA/QC)	3	samples	\$	30.00	\$ 90.00
Bromacil by Method E507 (primary samples + QA/QC)	3	samples	\$	142.00	\$ 426.00
Nitrates by Method E300.0 (primary samples + QA/QC)	3	samples	\$	25.00	\$ 75.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	1	day	\$	400.00	\$ 400.00
Vehicle Rental (1 vehicle for 1 day)	1	day	\$	55.00	\$ 55.00
Miscellaneous Field Supplies					\$ 50.00
SUBTOTAL MONTHLY COSTS					\$ 3,956.00
TOTAL ANNUAL COSTS					\$ 132,822.00

Long Term Monitoring for 75 years:
TOTAL MONITORING PROGRAM COST -- SOUTH BALLOON AREA **\$9,961,650.00**

^{a/} Estimated by Parsons based on revised sampling program (Table 4.22).

^{b/} VOCs = volatile organic compounds.

^{c/} PID = photo ionization detector.

^{d/} Metals analyses include arsenic, chromium, and lead.

SECTION 5

RECOMMENDATIONS FOR SYSTEMS OPTIMIZATION

DDJC-Sharpe and its environmental contractors have an effective RPO Phase I program in place. This program is characterized by monthly, quarterly, and/or annual reviews of the SVE systems, groundwater monitoring program, treatment plant performance, and assessment of progress toward ACLs for groundwater, together with annual recommendations for adjustments in the LTM program and groundwater extraction well pumping rates.

In addition to the Phase I efforts, DDJC-Sharpe also has undertaken studies to address site-specific or longer-term remedial optimization at the Depot, including evaluating the applicability of the STOP protocol in the decision process for termination of SVE system operation, and assessing the potential contribution of natural attenuation toward restoring groundwater quality at and downgradient from the facility (Radian, 1999b). These efforts are commendable, and may result in significant cost savings (e.g., through early termination of SVE system operation) without compromising ROD objectives.

The current RPO Phase II effort has reviewed available information, and has identified additional optimization opportunities that could enhance the cost-effectiveness and efficiency of remedial systems and the groundwater monitoring program at DDJC-Sharpe. This section reviews these opportunities, suggests additional data collection strategies to obtain supporting information for negotiations to be held during the 5-year ROD review, and provides estimates of potential cost savings associated with each opportunity. Suggestions for implementing these opportunities also are provided.

5.1 REVISE CONCEPTUAL MODEL AND DATA-PRESENTATION STRATEGY

Recommendation 1: Simplify the hydrogeologic CSM for DDJC-Sharpe as suggested in Section 2.5.

Rationale: *The current CSM (Section 2) over-emphasizes the relative importance of hydrostratigraphic units within the Victor and Laguna Formations. Though it has been demonstrated that the four currently designated monitoring zones at DDJC-Sharpe are hydraulically connected and have similar hydraulic characteristics, the current CSM perpetuates distinctions among horizons that may unnecessarily complicate the interpretation of contaminant fate and transport in the subsurface, and that may be contributing to a piecemeal remediation of COC plumes at and downgradient from the Depot. Simplifying the model so that it more correctly describes the separate “monitoring zones” as comprising different depth intervals within the same, hydraulically-interconnected, water-bearing unit, could clarify plume interpretations and encourage remediation and monitoring of the COC plumes independent of arbitrary monitoring zones.*

Implementation: *The proposed CSM revisions should be reviewed by the DDJC-Sharpe, environmental contractors, and the appropriate regulatory-agency personnel to confirm that use of a refined CSM will be effective for implementing ROD objectives. Once approved, incorporation of the model into the next annual groundwater monitoring report can be readily implemented at minimal cost (Table 5.1). If OUI data compilation, management, and reporting can be simplified for a single water-bearing unit, quarterly and annual reporting efforts for monitoring data could be streamlined, and associated costs incrementally reduced.*

TABLE 5.1
REMEDIAL OPTIMIZATION RECOMMENDATIONS SUMMARY
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Recommendation	Estimated Annual Cost Savings ^{a/}	Cost Savings Over Life Cycle ^{a/b/}	Difficulty of Implementation	Estimated Cost to Implement ^{a/}
Optimization of Conceptual Model and Data-Presentation Strategy				
Recommendation 1: Simplify the hydrogeologic CSM for DDJC-Sharpe.	TBD ^{c/}	TBD	Moderate – Requires regulatory approval.	\$1 K ^{d/}
Recommendation 2: Revise the data-presentation strategy for tracking COC concentrations and distributions in OU1 groundwater in the annual monitoring reports.	TBD	TBD	Low	\$1 K
Optimization of SVE System				
Recommendation 3: Select and implement site-specific soil cleanup goals.	TBD	TBD	Moderate – Requires regulatory approval.	\$5 K
Recommendation 4: Discontinue active SVE operations at sites P-1E and P-6A.	\$16 K	TBD	Moderate – Requires regulatory approval.	\$5 K
Recommendation 5: Focus SVE to TCE hot spots at the remaining active SVE site(s).	≤ \$24 K	TBD	Low	\$2 K
Recommendation 6: Eliminate offgas treatment of SVE vapor effluent based on system monitoring data.	≤ \$6.4 K	≤ \$160 K	Moderate – Requires regulatory approval.	\$1 K
Recommendation 7: Implement passive extraction of SVE systems during inactive periods of system cycling.	\$2.4 K	≤ \$28.8 K	Moderate – Requires regulatory approval.	\$1 K
Optimization of the OU1 Groundwater ETI Systems				
Recommendation 8: Optimize groundwater ETI systems for plume containment/hydraulic control. Permanently remove 18 existing extraction wells from service. Monitor rebound in inactive wells for one-year period (quarterly monitoring). Continue to monitor groundwater conditions to evaluate long-term plume stability.	\$193 K	>\$9.1 M	Moderate to high – Requires regulatory approval.	\$30 K
Recommendation 9: Remove Central Area “A”-zone treatment train from service. Discontinue disposal of treated water via injection wells and percolation ponds. Route all treated water to the SSJDC or Dynegy [®] lines for disposal.	TBD	TBD	Moderate to high – Contingent on Recommendation 8 and subject to regulatory approval	\$15 K

TABLE 5.1 (Continued)
REMEDIAL OPTIMIZATION RECOMMENDATIONS SUMMARY
REMEDIAL PROCESS OPTIMIZATION PHASE II EVALUATION
DDJC-SHARPE, CALIFORNIA

Recommendation	Estimated Annual Cost Savings ^{a/}	Cost Savings Over Life Cycle ^{a/b/}	Difficulty of Implementation	Estimated Cost to Implement ^{a/}
Recommendation 10. Consider bypassing the second of the twin stripping towers at the North Balloon and Central Area “B”/“C” GWTPs.	TBD	TBD	Low to moderate – Requires mechanical engineering evaluation of existing circuits.	\$10 K
Optimization of Groundwater Monitoring Program				
Recommendation 11: Revise the existing groundwater monitoring program in the South Balloon area in accordance with the recommended optimization strategy. Conduct a more rigorous spatial-statistical evaluation of the monitoring network at the South Balloon, and implement the results of the spatial evaluation.	\$116 K	\$8.7M	Moderate – Requires regulatory approval.	\$15 K
Recommendation 12: Optimize the groundwater monitoring programs at the North Balloon and Central Area.	\$230 K	\$5.9 M	Moderate – Requires regulatory approval.	\$50 K
Recommendation 13: Evaluate diffusion sampling as a supplemental or replacement technology for the micropurge sampling currently used in the LTM program.	TBD	TBD	Moderate – Requires evaluation of comparability and subsequent regulatory approval.	\$25 K
Recommendation 14: Review the current laboratory selection and auditing process to ensure the contract laboratory is consistently meeting all analytical method requirements, and that pricing for analytical services is competitive.	\$10 K	\$750 K	Low	\$1 K
TOTAL	\$598 K	\$24.6 M		\$160 K

^{a/} Estimated costs presented in constant (year 2000) dollars.

^{b/} Life cycle for SVE system is estimated to be a maximum of 12 years.

Life cycle for conceptual model, data presentation strategy, and operation of some elements of ETI systems is estimated to be 75 years.

Life cycle for groundwater monitoring program is estimated to be 75 years.

^{c/} TBD – To be determined.

^{d/} K – thousands of dollars. M – million of dollars.

1 **Recommendation 2:** In accordance with the discussion in Section 2.5, revise the data-
2 presentation strategy for tracking COC concentrations and spatial distribution in
3 groundwater in the annual monitoring reports for OU1, to thematically associate
4 concentrations with sampling locations, and to improve the assessment of plume
5 evolution through time.

6 Rationale: *Currently, plume evolution is tracked in the annual groundwater*
7 *monitoring reports for the fiscal year for which data are reported,*
8 *and compared only with the interpretation generated during the*
9 *previous year. Plumes are loosely interpreted by hydrostratigraphic*
10 *horizon, and variability in monitoring points sampled from year to*
11 *year can greatly influence interpretations of apparent annual*
12 *changes in plumes that may not be supported by the data. Because*
13 *plume evolution has not been tracked through the entire period of*
14 *remediation, it is difficult to assess remedial progress. Plotting*
15 *concentration data by sampling location in a thematic format for*
16 *sequential monitoring periods since groundwater ETI system startup*
17 *dramatically improves a reviewer's ability to understand and*
18 *interpret changes that can be attributed to changes in chemical*
19 *concentrations and spatial distribution versus distortions*
20 *attributable to changing sampling designs through time. The*
21 *thematic data-presentation method suggested in Section 2.5 also can*
22 *support qualitative optimization of the LTM monitoring program,*
23 *thereby ensuring that temporal concentration data are collected*
24 *consistently at key monitoring locations in order to assess plume*
25 *stability through time and to evaluate the effects of the groundwater*
26 *ETI systems on plume magnitude and extent.*

27 Implementation: *The proposed data-presentation strategy is readily implemented, and*
28 *should not materially affect the cost of reporting that is routinely*
29 *conducted for DDJC-Sharpe (Table 5.1).*

5.2 OPTIMIZATION OF SVE SYSTEMS

Recommendation 3: Implement site-specific soil cleanup goals at sites P-1A/P-1B/P-1C, P-1E, and P-6A.

Rationale: *The ROD-specific soil-vapor cleanup level 350 ppbv for TCE apparently was derived on the basis of Henry's Law, which describes the concentration of a substance dissolved in the aqueous phase at equilibrium with its vapor phase (Appendix C). The assumptions required for this derivation are unrealistic, and lead to cleanup standards for TCE in soil vapor that are overly conservative. In addition, several attenuation mechanisms, including volatilization, sorption to soil, dilution, dispersion, and chemical or biological degradation, are capable of decreasing the mobility or concentrations of CAH in the subsurface.*

The results of an evaluation of site-specific conditions in the vadose zones at sites P-1A/P-1B/P-1C, P-1E, and P-6A indicate that TCE in soil, in equilibrium with vapor-phase concentrations of TCE in the range of 600 to 620 ppbv, could remain in the vadose zone at each of the three SVE sites without causing further migration of TCE to the water table at concentrations that would exceed the ROD ACLs. These proposed site-specific RAOs for CAH in soil are about 70 percent higher than the current RAOs (Table 3.4), while remaining protective of groundwater quality. Adoption of site-specific RAOs could result in the SVE systems achieving soil cleanup objectives in less time than currently projected, at lower cost.

Implementation: *Modification of the soil cleanup goals specified in the Basewide ROD (ESE, 1996) will require concurrence by the regulatory agencies. Dialogue should begin immediately to propose that site-specific cleanup goals be substituted for the generically-derived goals in the ROD. Periodic monitoring of the SVE systems during operation should then provide the data necessary to optimize system operations. When the results of soil-vapor monitoring indicate that*

1 the concentrations of VOCs in soil vapor at a specific VMP no
2 longer exceed vapor-phase soil cleanup criteria, the SVE system in
3 that area could be shut down, because the mass of VOCs remaining
4 in that soil volume would be unlikely to represent a continued
5 potential threat to groundwater. Soil-vapor monitoring should be
6 continued for some period of time following system shut-down to
7 evaluate whether the concentrations of VOCs in soil vapor increase,
8 as volatile constituents sorbed to soil or within the soil matrix diffuse
9 into the soil pore spaces (the “rebound” effect). In some cases, the
10 concentrations of VOCs may continue to rebound above screening-
11 level soil vapor criteria during equilibrium (shut-down) testing. In
12 such cases, an approach similar to the STOP protocol (Castle AFB,
13 1999) should be pursued to evaluate the relative costs/benefits of
14 continued operation of SVE systems having marginal extraction
15 rates and high unit costs for VOC mass removal.

16 **Recommendation 4:** Discontinue active SVE operations at sites P-1E and P-6A.
17 Implement STOP protocol at these sites.

18 Rationale: Examination of cumulative mass-removal curves for SVE sites P-1E
19 and P-6A indicate that the rate of mass removal at each site has
20 become asymptotic (Section 4.1.2.4), and that little additional TCE
21 mass could be removed from the vadose zone at these sites with
22 continued operation of the SVE systems. As of July 2000, SVE
23 operations at sites P-1E and P-6A had removed approximately one-
24 half pound of TCE from the subsurface. As a consequence of the low
25 mass of TCE removed from the vadose zone at sites P-1E and P-6A,
26 the estimated unit costs per pound of TCE removed from the vadose
27 zone at these sites are about \$104,000 per pound and \$188,000 per
28 pound, respectively.
29 The elements required by the Base-wide ROD for terminating SVE
30 operations at these sites have been achieved:

- 1 1. *The technical limits of the SVE systems appear to have been*
2 *reached, as demonstrated by asymptotic mass removal.*
- 3 2. *The duration of continued groundwater ETI at the South Balloon*
4 *and Central Area, where sites P-1E and P-6A are located, is*
5 *anticipated to be several decades (at a minimum); and the total*
6 *costs will be in the millions of dollars. The duration and cost of*
7 *continued groundwater ETI are likely to be unaffected by the*
8 *migration of the little TCE mass remaining in the vadose zone at*
9 *the two sites that might occur, in the absence of continued SVE*
10 *operation.*
- 11 3. *The incremental costs of continued operation of the SVE systems*
12 *at the sites are likely to be well over \$100,000 per pound of TCE*
13 *removed from the vadose zone (Section 4.1.2.4). By comparison,*
14 *the incremental cost of removing one pound of TCE from*
15 *groundwater, using the groundwater ETI systems, is on the order*
16 *of \$3,100 (Section 4.2.2.1).*

17 *Assuming that the SVE systems at sites P-1E and P-6A can be taken*
18 *off-line, an estimated two-thirds of the annual O&M costs for the*
19 *SVE systems (approximately \$16,000 in constant 2000 dollars) could*
20 *result. Because the total length of time that might be required to*
21 *achieve the current ROD-specified RAOs for TCE in soil vapor at*
22 *the two sites is not known, the total potential cost savings that might*
23 *result from implementation of this recommendation cannot be*
24 *estimated.*

25 Implementation: *Termination of SVE operations at any site will require concurrence*
26 *by the regulatory agencies. Dialogue should begin immediately to*
27 *examine the operational performance at sites P-1E and P-6A, and to*
28 *evaluate the applicability of the ROD-specified termination*
29 *procedures and the STOP protocol. If it is determined that the*
30 *requirements of the ROD have been achieved, whether in terms of*

1 *the current RAOs for TCE in soil vapor, or for the proposed*
2 *alternative, site-specific RAOs, then the SVE systems could be shut*
3 *down. Soil-vapor monitoring should be continued for some period*
4 *of time following system shut-down to evaluate whether the*
5 *concentrations of VOCs in soil vapor increase (the “rebound”*
6 *effect). If significant rebound is observed, additional actions*
7 *(possibly including returning the system(s) to service for a period of*
8 *time) should be considered. After rebound monitoring has been*
9 *completed, proceed with implementation of the STOP protocol, as*
10 *described by Radian (2000b).*

11 **Recommendation 5:** Focus SVE at TCE hot spots in the vadose zone at the remaining
12 SVE site(s).

13 Rationale: *Adoption of alternative, site-specific RAOs for concentrations of*
14 *TCE in the range of 600 to 620 ppbv for TCE in soil vapor (Table*
15 *3.4) would reduce the volumes of soil requiring SVE remediation at*
16 *each of the three SVE sites. These soil hot spots could then be*
17 *targeted for SVE remediation, which probably could be*
18 *accomplished using systems smaller than those currently designed.*
19 *The SVE systems, as currently installed and operated, enable*
20 *individual wells and circuits to be removed from service. If the*
21 *extent of TCE in the subsurface at the three SVE sites were defined*
22 *to identify those areas containing TCE at vapor-phase*
23 *concentrations that exceed alternative, site-specific RAOs, SVE*
24 *system operations could be modified so that only those VEWs*
25 *operating in areas of exceedance would remain in service.*
26 *Increased extraction rates in a smaller number of wells would result,*
27 *and the pore-volume exchange rate could be increased, potentially*
28 *shortening the period of time that the SVE systems would remain in*
29 *operation.*

30 Implementation: *Because the SVE systems have been operational for over two years,*
31 *it would be most cost-effective to optimize the operating SVE systems*

1 *based on observed concentrations of VOCs in the extracted vapor*
2 *stream of individual VEWs. If higher cleanup goals can be*
3 *negotiated, VEWs extracting soil-vapor with relatively low*
4 *concentrations of VOCs could be taken off line, or their flow rates*
5 *could be reduced, and venting in hot spots could continue at*
6 *maximum design flow rates. The cost to implement this*
7 *recommendation would be negligible, as the data required to*
8 *optimize the SVE systems are collected as part of routine system*
9 *monitoring (Table 5.1).*

10 **Recommendation 6:** Based on results of SVE system monitoring, eliminate offgas
11 treatment of SVE vapor effluent.

12 Rationale: *The results of influent vapor-stream sampling completed by Radian*
13 *(2000b) during system prove-out indicate that direct discharge of*
14 *untreated vapor-phase effluent from SVE operations at the SVE sites*
15 *probably would not introduce volatile COC mass to the atmosphere*
16 *at levels in excess of current regulatory limits. Therefore, GAC*
17 *treatment of extracted soil vapor may not be necessary. Elimination*
18 *of GAC treatment of the SVE vapor effluent stream at all three sites*
19 *could generate total cost savings of as much as \$160,000 in constant*
20 *(2000) dollars (Table 5.1).*

21 Implementation: *This possible elimination of offgas treatment could be evaluated*
22 *during operational periods for each of the SVE systems by*
23 *periodically collecting and analyzing samples of the extracted vapor*
24 *from the influent lines to the treatment system at each SVE site. If*
25 *the results of monitoring of the vapor streams influent to the vapor-*
26 *treatment system indicate that the discharge limit established by the*
27 *SJVUAPCD (less than 2 pounds of VOC mass discharged to the*
28 *atmosphere per day), then the GAC treatment system could be*
29 *bypassed, with the SVE blower unit discharging directly to the*
30 *atmosphere.*

Recommendation 7: Implement passive extraction of SVE systems during inactive periods of system cycling.

Rationale: *The mass-removal rate of a continuously operating passive SVE system is estimated to be approximately one-tenth the mass removal rate of a continuously operating active SVE system. Implementation of passive SVE in conjunction with continued active SVE operations could reduce the length of time required to achieve RAOs in soil at the three DDJC-Sharpe sites by as much as 10 percent, resulting in a 10-percent cost savings for OM&M of the SVE systems (Table 5.1).*

Implementation: *The SVE systems at DDJC-Sharpe are operated in cycles, with active SVE occurring at only a single site at any given time. This method of operation presents an opportunity to implement passive SVE treatment technology at the two inactive SVE sites, concurrently with active SVE treatment proceeding at the other site. Only minor modifications would be required to adapt the SVE systems for periodic use as passive venting systems. During periods of inactivity at an SVE site, a valve or vent in the manifold, or at individual wellheads, could be left open to the atmosphere, thereby allowing free exchange of air and vapor between the atmosphere and the SVE well system. A modification of this type could be implemented at little or no additional cost (Table 5.1).*

5.3 OPTIMIZATION OF THE OU1 GROUNDWATER ETI SYSTEM

Recommendation 8: Plume containment and hydraulic control of contaminant migration, using the minimum number of wells necessary to effect plume capture, should be the primary goal of groundwater ETI activities at DDJC-Sharpe. The results of a capture-zone evaluation, completed for the groundwater extraction systems at DDJC-Sharpe, indicate that if the extraction systems are optimized for plume containment/hydraulic capture, 10 of the existing wells in the North Balloon area, 5 of the existing wells in the Central Area, and 9 of the existing wells in the

1 South Balloon area, all pumping at recent historic rates, should be able to achieve
2 plume containment and hydraulic control of the dissolved CAH plumes. This
3 would enable 18 of the currently-operating groundwater extraction wells at DDJC-
4 Sharpe to be removed permanently from service. Well-specific recommendations
5 are summarized in Table 4.15.

6 Rationale: *Little or no contaminant mass removal is occurring at a number of*
7 *the currently-active groundwater extraction wells, as a consequence*
8 *of low rates of groundwater withdrawal, low TCE concentrations in*
9 *extracted groundwater, or both. Based on examination of historic*
10 *changes in contaminant concentrations in groundwater extraction-*
11 *well effluent, the minimum times required to achieve ACL*
12 *concentrations of COCs in groundwater are projected to range from*
13 *11 years (in the Central Area) to about 75 years (in the South*
14 *Balloon area), although longer periods of time may well be required*
15 *(Section 4.2.2.1). Several factors are likely to extend the time period*
16 *needed to attain cleanup goals throughout the plume to periods of*
17 *decades to perhaps more than 100 years, including slow desorption*
18 *of contaminants from the soil matrix, and slow release of*
19 *contaminants by diffusion from low-permeability strata or from*
20 *“dead-end” pore spaces, and from the solid matrix. The primary*
21 *capabilities that groundwater extraction-and-treatment systems offer*
22 *at most sites are hydraulic control of the dissolved contaminant*
23 *plume, and/or containment of the source zone. Therefore, the*
24 *preferred strategy for such sites is to pump at the lowest rate*
25 *necessary to achieve the desired degree of capture of the*
26 *contaminant flux from the source zone(s). The rate of contaminant*
27 *mass removal is then equal to or only slightly greater than the mass*
28 *flux emanating from the source zone under natural conditions.*
29 *Assessment of the natural-attenuation potential at DDJC-Sharpe*
30 *(Section 2.3.3) indicates that biodegradation processes are*
31 *destroying CAH mass in the subsurface at appreciable rates. Most*

1 of the extraction wells recommended for removal from operation on
2 the basis of the capture-zone optimization are also marginal or
3 ineffective at removal of contaminant mass. If the current
4 groundwater extraction systems are modified to optimize
5 containment and capture of contaminants, the relatively ineffective
6 mass-removal capabilities of the extraction systems will be
7 supplemented by natural-attenuation processes.

8 If the groundwater extraction systems are optimized for plume
9 containment and hydraulic control, annual cost savings on the order
10 of \$193,000 (in constant 2000 dollars). Assuming that the optimized
11 groundwater extraction systems remain in service for the minimum
12 periods of time projected for each system to achieve groundwater
13 RAOs (about 40 years for the North Balloon system, 11 years for the
14 Central Area system, and 75 years for the South Balloon system),
15 total savings in excess of \$9M (in constant 2000 dollars) could result
16 (Table 5.1).

17 Implementation: Optimization of the extraction system for plume containment and
18 hydraulic control will require regulatory concurrence. If
19 termination of operation of one or more extraction wells is
20 approved, the subject extraction wells should be taken off line, and
21 rebound monitoring of COC concentrations should be initiated, to be
22 conducted at an agreed-upon frequency to assess the effects of
23 removing the wells from service. The monitoring schedule should be
24 developed with consideration of solute travel times from upgradient
25 areas, with quarterly monitoring for a one-year period as a
26 minimum. Rebound monitoring would provide confirmation that
27 removal of these wells from the extraction system will not adversely
28 affect remedial progress. In addition, the results of periodic
29 monitoring using the existing monitoring network should be
30 critically evaluated, to assess whether removal of wells from service
31 allows contaminant migration and expansion of the CAH plumes to

1 occur. The cost to implement rebound monitoring at 18 wells for a
2 one-year period, assuming that the current (quarterly) sampling
3 frequency for VOCs at each well is continued, is provided in Table
4 5.1.

5 **Recommendation 9:** Remove Central Area “A”-zone treatment train from service.
6 Discontinue disposal of treated water via injection wells and percolation ponds.
7 Route all treated water to the SSJIDC or Dynegy® lines for disposal.

8 Rationale: This recommendation is contingent upon implementation of
9 Recommendation No. 8 (above). TCE mass-removal rates at the
10 Central Area “A”-zone GWTP have become asymptotic, suggesting
11 that little additional TCE mass can be removed by continued
12 operation of this system (Section 4.2.4). Evaluation of hydraulic
13 containment and contaminant capture in the Central Area (Section
14 4.2.2.2) indicates that the “A”-zone extraction wells in the Central
15 Area could probably be removed from service. Currently,
16 groundwater from the “A” zone in the Central Area is managed and
17 disposed separately from groundwater extracted from the “B” and
18 “C” zones, as a consequence of elevated levels of arsenic in
19 groundwater extracted from wells completed in the “A” monitoring
20 zone. If “A”-zone extraction wells in the Central Area are removed
21 from service, the Central Area “A”-zone treatment train could be
22 taken off-line, and arsenic in disposed water would no longer be an
23 issue. This improvement could also generate efficiencies and cost
24 savings, although the potential range of savings is difficult to
25 quantify

26 **Recommendation 10:** Consider bypassing the second of the twin stripping towers at the
27 North Balloon and Central Area “B”/“C” GWTPs.

28 Rationale: The results of sampling of extracted groundwater (Section 4.2.2)
29 suggest that the concentrations of VOCs in the influent streams to
30 the GWTPs at the North Balloon and the Central Area “B”/“C”-

zone treatment trains are low enough that a single air-stripping tower would be sufficient to treat VOCs in extracted groundwater to levels that would meet RAOs for discharge of treated water. The concentrations of VOCs in a water sample collected from the lines from the line between the twin air-stripping towers at the Central Area "B"/"C"-zone GWTP were below detection limits, indicating that a single pass through an air-stripping plant was sufficient to treat extracted groundwater. Based on the concentrations of VOCs historically detected in the influent stream to the North Balloon GWTP, it is anticipated that a single stripping tower also would be sufficient to treat groundwater extracted from the North Balloon area. If the GWTP air-stripping circuits at the North Balloon and Central Area "B"/"C"-zone GWTPs could be re-routed inexpensively to bypass the second tower in each circuit, long-term O&M costs associated with operating two air-stripping towers could be reduced or eliminated. However, potential cost savings associated with this modification are difficult to quantify.

Implementation: It is likely that an engineering evaluation of the existing circuits at the North Balloon and Central Area GWTPs would be required prior to implementing this recommendation. If implementation of the recommendation is feasible, piping at the plants would need to be re-routed, and the GWTP controls likely would require modification. Therefore, implementation of this recommendation should only proceed if the projected cost savings appear likely to exceed the engineering and implementation costs.

5.4 OPTIMIZATION OF GROUNDWATER MONITORING PROGRAM

Recommendation 11: Revise the existing groundwater monitoring program in the South Balloon area in accordance with the recommended optimization strategy described in Section 4.3. Conduct a more rigorous spatial-statistical evaluation of the monitoring network at the South Balloon, and implement the results of the spatial evaluation.

1 Rationale:

2 *The primary objectives of monitoring are to: 1) evaluate long-term*
3 *temporal trends in contaminant concentrations at one or more points*
4 *within or outside of the remediation zone, as a means of monitoring*
5 *the performance of the ETI system (temporal evaluation); and 2)*
6 *evaluate the extent to which contaminant migration is occurring,*
7 *particularly if a potential exposure point for a susceptible receptor*
8 *exists (spatial evaluation). As discussed in Section 4.3, a reduced*
9 *monitoring network or changes in the frequency of sampling may be*
10 *adequate to meet the two primary objectives of monitoring at the*
11 *South Balloon area, at reduced cost and with little or no loss of*
12 *information.*

13 *The current estimated annual cost of the groundwater monitoring*
14 *program at the South Balloon is approximately \$250,000. If the*
15 *optimized monitoring network is implemented as recommended*
16 *(Section 4.3), an annual cost savings of approximately \$116,000 (45*
17 *percent) could be realized. (Table 5.1). Total cost savings over the*
18 *projected 75-year duration of monitoring at the South Balloon could*
19 *be more than \$8.7M (in constant 2000 dollars). Additional*
20 *efficiencies may be realized if more rigorous statistical procedures*
21 *(e.g., geostatistics) are utilized to evaluate spatial aspects of the*
22 *monitoring network.*

23 Implementation:

24 *Changes to the LTM program at the South Balloon will require*
25 *concurrence by the regulatory agencies. Dialogue should begin*
26 *immediately to examine the procedures used in evaluating the*
27 *current monitoring program and developing recommendations for*
28 *revisions. If the recommendations are accepted, review the*
29 *sampling and analytical schedule annually to ensure that individual*
30 *monitoring points are sampled as appropriate.*

31 **Recommendation 12:** Perform an optimization evaluation for the monitoring networks
at the North Balloon and Central Area in accordance with the procedures and
decision logic described in Section 4.3.

1 Rationale: The results of the optimization evaluation completed for the
2 monitoring network at the South Balloon area demonstrate that if
3 appropriate revisions are made, the size of the network, and/or the
4 frequency of monitoring can be reduced, thereby producing
5 efficiencies and cost savings with potentially little or no loss of
6 information. If the results of optimizing the monitoring programs at
7 the North Balloon and Central Area are similar to the results
8 obtained in the evaluation of the South Balloon monitoring program,
9 annual cost savings of approximately \$115,000 for each network
10 might result. This is equivalent to a total savings of approximately
11 \$5.9M (in constant 2000 dollars) over the projected duration of
12 monitoring at the North Balloon (40 years) and Central Area (11
13 years).

14 Implementation: Review the monitoring network optimization approach with
15 regulators to attain regulatory approval prior to implementation.
16 Perform a qualitative evaluation to identify those monitoring points
17 that must remain in the monitoring program. Perform a temporal
18 analysis on the remaining wells in order to identify contaminant
19 concentration trends through time. Based on the results of the
20 temporal analysis, identify those wells that are not providing useful
21 temporal information. Perform the spatial analysis on all wells
22 currently included in the monitoring program to identify spatially
23 redundant wells. If a monitoring well is identified as providing
24 insignificant temporal and spatial information, and if there is no
25 qualitative reason to maintain sampling of the well, consider
26 removing the well from the monitoring program, changing the
27 analytical requirements, or reducing the frequency of sampling for
28 that well.

29 **Recommendation 13:** Evaluate diffusion-sampling technology as a supplemental or
30 replacement method for the micropurge sampling technology currently used in the
31 LTM program.

1 Rationale:

2 *The pilot-scale evaluation of diffusion sampling recently completed*
3 *at DDJC-Tracy demonstrates that this technology is a viable option*
4 *for VOC monitoring. This technology can provide analytical results*
5 *comparable to current sampling methods, is relatively simple to*
6 *implement and maintain, would reduce generation of investigation-*
7 *derived waste, and would reduce overall LTM program costs. The*
8 *cost per sample, collected using diffusion-sampling techniques, is*
9 *approximately one-third to one-fifth the cost per sample collected*
10 *using conventional or micropurging techniques. In the absence of*
11 *detailed information regarding the locations and numbers of*
12 *monitoring wells equipped with dedicated pumps, it is not possible to*
13 *estimate the potential cost savings that might result from*
14 *implementation of diffusion-sampling technology. .*

15 Implementation:

16 *Diffusion sampling probably would not be appropriate for use at all*
17 *of the monitoring wells currently included in the DDJC-Sharpe LTM*
18 *program. Factors to consider include the screen length of the*
19 *monitoring wells, the frequency of sample collection, the analytes*
20 *that are evaluated at each well (the technology currently has been*
21 *developed for VOC sampling only), and whether the well is already*
22 *equipped with dedicated sampling equipment. Prior to full-scale*
23 *implementation of the technology, it will be necessary to evaluate the*
24 *comparability of monitoring data generated using the current*
25 *sampling technology, and diffusion-sampling data. This should be*
26 *accomplished by collecting paired samples for VOC analysis at a*
27 *subset of the monitoring wells that are currently sampled using*
28 *conventional techniques and diffusion sampling, and comparing the*
29 *results of the two sampling methods. If the results are similar, or if*
30 *the diffusion sampler result is higher than the conventional method*
 result, diffusion sampler use may be appropriate for that particular
 well. Assuming that comparisons of analytical results are completed

1 for 40 wells, it is estimated that this evaluation would require
2 approximately \$25,000 to implement.

3 **Recommendation 14:** Review the current laboratory selection/auditing process to ensure
4 the contract laboratory is consistently meeting all analytical method requirements,
5 and that pricing for analytical services is competitive.

6 Rationale: *Deficiencies in pricing and customer service of the incumbent*
7 *analytical laboratory were identified during the RPO investigation.*
8 *A comparison of laboratory analytical costs indicated that current*
9 *CalTEST analytical costs could be reduced by as much as \$10,000*
10 *per year if a competing laboratory were used for VOC analyses*
11 *(Method SW8260B) alone. This price difference potentially could*
12 *save DDJC-Sharpe a total of approximately \$750,000 during the*
13 *projected lifetime (75 years) of the LTM program. Furthermore, QC*
14 *and customer service issues identified during the RPO investigation*
15 *suggest that laboratory auditing/selection process should be*
16 *reviewed.*

17 Implementation: *The annual laboratory review process is already in place, and*
18 *therefore the cost to implement more rigorous oversight of*
19 *laboratory subcontractors would be negligible. Market research on*
20 *competitive analytical costs would require minimal effort (Table*
21 *5.1).*

22 As part of this DLA RPO initiative, implementation of the recommendations made in
23 this section should be considered and carried out, as appropriate, by the facility and its
24 contractors. The RPO program at DDJC-Sharpe should continue the established
25 performance evaluation framework currently in place, and should be extended as
26 necessary to assess the effectiveness of the optimization efforts implemented as a result
27 of the recommendations presented herein. These events could be implemented in
28 accordance with the following general schedule:

Item	Timeframe	Schedule
Review of Draft RPO Report and DLA/DDC/AFCEE concurrence	To be completed 3 weeks after posting on the DLA web site	12 March 2001
RPO briefing of DDJC-Sharpe, the environmental contractor (Radian/URS), and the regulatory agencies	Immediately following review	14 March 2001
Implementation of recommendations	Beginning within 3 months of briefing	15 June 2001
Optimized systems operation	14 months following implementation	June 2001 – August 2002
Data collection and analysis	Quarterly through implementation period	July 2001, October 2001, January 2002, April 2002, July 2002
Data interpretation	1 month after quarterly data collection/analysis	August 2001, November 2001, February 2002, May 2002, August 2002
Follow-up meetings with regulatory agency(ies)	Quarterly or as required during implementation and trial operating period	September 2002
5-Year ROD Review	10 years after Comprehensive ROD was issued (1996)	2006

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